NUCLEAR ENGINEERING

VOL. 1 NO. 7 OCTOBER, 1956

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Proprietors:
TEMPLE PRESS LIMITED

Chairman and Managing Director:
ROLAND E. DANGERFIELD

Editorial Director:
A. P. CHALKLEY, B.Sc.(Eng.)

Editor:
E. N. SHAW, B.Sc.

Head Office:
BOWLING GREEN LANE, LONDON, E.C.1
Telephone: Terminus 3636 (Private Exchange).
Inland Telegrams: "Pressimus London Telex."
Telex: 2-3039.
Cables: "Telex 2-3039=Pressimus London."

ANNUAL SUBSCRIPTION RATE 42/-
(Canada and U.S.A. $7.00) postage included.

PUBLISHED IN GREAT BRITAIN BY TEMPLE PRESS LIMITED, LONDON, ENGLAND

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Ekco Electronics have made vital contributions to the instrumentation of the existing reactors at Harwell and Calder Hall, and are responsible for the nucleonic instrumentation of the reactors under construction in Australia, and at Harwell and Dounreay. This marks yet another important step in the long line of Ekco achievements in nucleonic measurement—a field in which we were pioneers and in which we continue to lead.

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NUCLEAR ENGINEERING VOL. I NO. 7 OCTOBER, 1956

EDITORIALS

The First Large-Scale Nuclear Power Station

POWER from the world's first large-scale nuclear generating station will be switched into the grid system of the United Kingdom by Her Majesty the Queen on October 17, but the significance of the ceremony rests not in the electricity generation *per se* nor in the specific contribution to the energy needs of the country. The real significance of Calder Hall lies elsewhere and must be taken in conjunction with another notable event in October, viz., the completion of the quotations for two complete nuclear power stations submitted by four separate concerns to the C.E.A. We shall see not merely the opening of a single power station but the inauguration of a comprehensive programme which will assure an ample supply of energy in the years to come.

The Calder Hall station will ultimately comprise four reactors and two turbine houses containing four turbines each, but in October one unit only will be operating at full power. The second reactor system of Calder "A" lags approximately six months behind the first which began commissioning trials in May, and the first of Calder "B" will be ready approximately twelve months later, followed by the fourth unit six months after that. Although the individual components of Calder "A" No. 1 have now been successfully tested, power will not be fed into the grid system even experimentally until October 17.

It must be remembered that, although this day will mark the official opening of the first reactor power station designed to produce tens of MWs of electricity, this will not be the first utilization of heat produced in the fission process. Both the U.S.A. and the U.S.S.R. have generated small quantities of electricity from atomic energy, and even as early as 1951 waste heat from BEPO was used for space heating. Calder Hall, therefore, is not the first useful-heat producing reactor, and whilst electricity generation is an important part of the project the reactor designs have been optimized for the production of plutonium.

Power reactors and production reactors of the gas-cooled, graphite-moderated type do not differ basically in design, the quantity of plutonium produced being proportional to the heat generated. Production demands a high heat release with a low coolant inlet temperature and frequent reprocessing of fuel elements, whereas economic heat generation demands high reactor temperatures and maximum fuel-irradiation times. The high-temperature requirement implies different structural materials with probably poorer neutron economy and hence a lower conversion factor, and the higher pressure of the coolant can better be accommodated with a more compact core design for a given thickness of the pressure vessel wall, similarly leading to poor neutron economy. On the other hand, long fuel-element life requires high reactivity in the clean, cold condition and the value of the plutonium produced figures significantly in the overall costing. In the main, therefore, the differences in design can be broken down into details of core construction, heat transfer conditions and operational programming.

The requirement for a large plutonium production facility stems chiefly from military considerations, although pure fissile material is necessary for the development of advanced types of reactor system. It is improbable, however, that the Calder Hall and Chapel Cross projects would have been undertaken for peaceful purposes only, as the demand for plutonium for power reactors can almost certainly be met from the natural-uranium-fuelled power stations. It is improbable that a detailed costing will be given of the electricity produced at Calder Hall but neither will it be significant. Much of the power produced on the site will be fed into other atomic energy projects such as the Windscale plant alongside. The station efficiency is not high, heat to electricity is calculated to be 20-21% with approximately 20% of the total generated capacity fed back to supply power to the auxiliaries. Only a small fraction of the heat produced will be available in the form of electricity for sale to the C.E.A.

Nevertheless, Calder Hall represents the first proving of a power reactor type, the gas-cooled, graphite-moderated, natural-uranium-fuelled reactor on which the United Kingdom's nuclear power programme will be based for many years to come. The U.K.A.E.A. has concentrated on this type supported by a very large cross-section of British industry, and by its single-mindedness of purpose has produced a prototype which has supplied the design experience and will provide the operational data for a group of stations to be built by 1965 with an output which even conservative estimates place as 5,000 MW, involving a capital expenditure of £500 million.

There were many, particularly in the early days, who doubted the wisdom of the choice and who felt convinced that the lone pursuance of this "simple" reactor type would inevitably saddle the country with a series of effete systems which would leave the U.K. a long way behind in the international race to produce economic nuclear power. Even accepting the possibility of the gas-cooled reactor proving to be a satisfactory type for a short period, some felt that other systems should be given equal priority in the development and prototype stages. Considerable effort has been devoted to feasibility studies on a number of types, and work at Dounreay has now reached the stage

EDITORIALS (*Continued*)

when the upper half of the containment sphere can be completed; but only on the Calder type has the full design and constructional effort of the U.K.A.E.A. and industry been employed. Events have proved that the original decisions taken were not only sound but have led to commercial designs with performances greatly exceeding initial expectations. Over the past three years the number of sceptics has steadily decreased and there is now universal approval of the British formulated programme and general recognition that for large scale electricity production by atomic energy Britain is leading the world.

Calder Hall by itself is a testimony to British engineering skill and ingenuity and is the most advanced structure in nuclear engineering that exists in the world today. But by itself it would remain a technical curiosity. Coupled with the tremendous national effort that has been exerted to complete the design of the world's first economic nuclear power station, it stands as one of the most important milestones on Britain's industrial road.

This tangible result of seven years of research and three years of construction means that we can look forward with complete confidence to the day when nuclear energy will form the basis of our power generation with all the promise that this holds.

A Message from the Prime Minister, The Rt. Hon. Sir Anthony Eden, K.G., M.C., M.P.

10 Downing Street
Whitehall

Of all the events which have taken place in this year 1956, history may remember longest the day when Calder Hall began to feed electricity into the national grid network. For the first time anywhere in the world nuclear energy will be used to supply electricity on a large scale. This will be a memorable day in man's forward march. It will be the outcome of ten years of sustained work by British scientists and engineers.

In 1946 we started our development programme with few resources except the knowledge stored in the brains of a handful of scientists. Their faith and their perseverance have opened up the prospect of a new industrial era. That new era will be rich in opportunities for those countries which have the skill and the enterprise to seize them. Calder Hall shows that we have both. We have made a splendid start and I am confident that we will not fall behind in the race in which we are engaged.

Anthony Eden

The U.K.A.E.A and Industry

WITHIN three years of the first breaking of ground at the Calder Hall site, steam was generated by the first reactor system. Leaving aside the technical problems still unsolved when work began, this was no mean feat, particularly when one considers that normal constructional time for a conventional power station is five years. Whilst it is difficult to fix an exact date for the beginning of design work, it would not be unreasonable to postulate a total time of five years, which should be compared with seven years for a conventional station including only minor novel features.

This speed in development and construction could scarcely have been achieved with any other organization than that adopted and without the fullest co-operation of all parties concerned. The industrial group of the U.K.A.E.A., as the responsible design and construction authority, was able to call on all branches of industry, who unstintingly drew on their resources to maintain the tight schedule that had been planned. No one company or group of companies bound together other than by a national authority, with direct access to the Government and the Treasury, could have approached their programme figures.

Keynotes to the project's success were the early freezing of design parameters with a rigid disregard for new ideas brought forward after the freezing date and the absolute priority given to the work by the contracting companies. At all times perfectionism was subordinated to the necessity for fitting into a planned programme, and one of the main tasks of the staff of the A.E.A. concerned the overall logistics. It should not be inferred that quality of workmanship suffered, and Calder Hall contains some fine examples of precision heavy engineering.

Such a concentration of effort cannot be accomplished, however, without cost, and many companies were forced to neglect other fields of engineering. In "other" should also possibly be included development work on the industrial nuclear power stations, in that, although experience gained on the Calder Hall project was of great value to those deeply engaged who were also consortium members, they had less effort to spare for taking advantage of this experience—made available to the entire industry—in the development of more advanced techniques. It can also be argued that those intimately involved in details of the Calder construction were less able to strike out into original lines of approach.

This all-out national effort is without precedent in peacetime and cannot be repeated in this field. Contracting companies will have, in general, their own atomic energy commitments which will demand first priority, and other fields of engineering cannot be allowed to suffer for future reactor projects. A further influencing factor is the spread of nuclear-engineering knowledge, which can no longer be considered concentrated inside the U.K.A.E.A., and the advent of commercial competition which forces companies into a more insular attitude and requires effort to be devoted almost exclusively to the reactor systems offering the greatest financial turnover in the not-too-distant future. We cannot, therefore, expect the same rapid progress with, say, the sodium-graphite reactor if this is chosen as the stage 2 type.

Quite apart from there being less available industrial effort for future prototype production work, now that thoroughly satisfactory designs have been completed for gas-cooled, graphite-moderated stations industry will be loath to embark on a new reactor type design for a long time to come unless the probability of a considerable economic improvement is high. Even then some rights over the techniques developed will be expected.

There will be many who will regret the passing of the day when the atomic energy programme was controlled from one centre and when the whole of the country's resources could be concentrated on the Authority's chosen projects, but the principle of an autocracy is only sound when all interested parties approve and when contracting members are free to exchange ideas, but as soon as competition develops and contractors are able to organize design teams of strength equivalent to the centre the condition no longer holds. This situation is exacerbated when the ultimate customer is also a large organization with a mind of its own. Some duplication of effort is then inevitable; but, on the other hand, without competition a programme soon either loses impetus or becomes narrow in outlook. The high quality of the consortia's designs would indicate that competition is desirable.

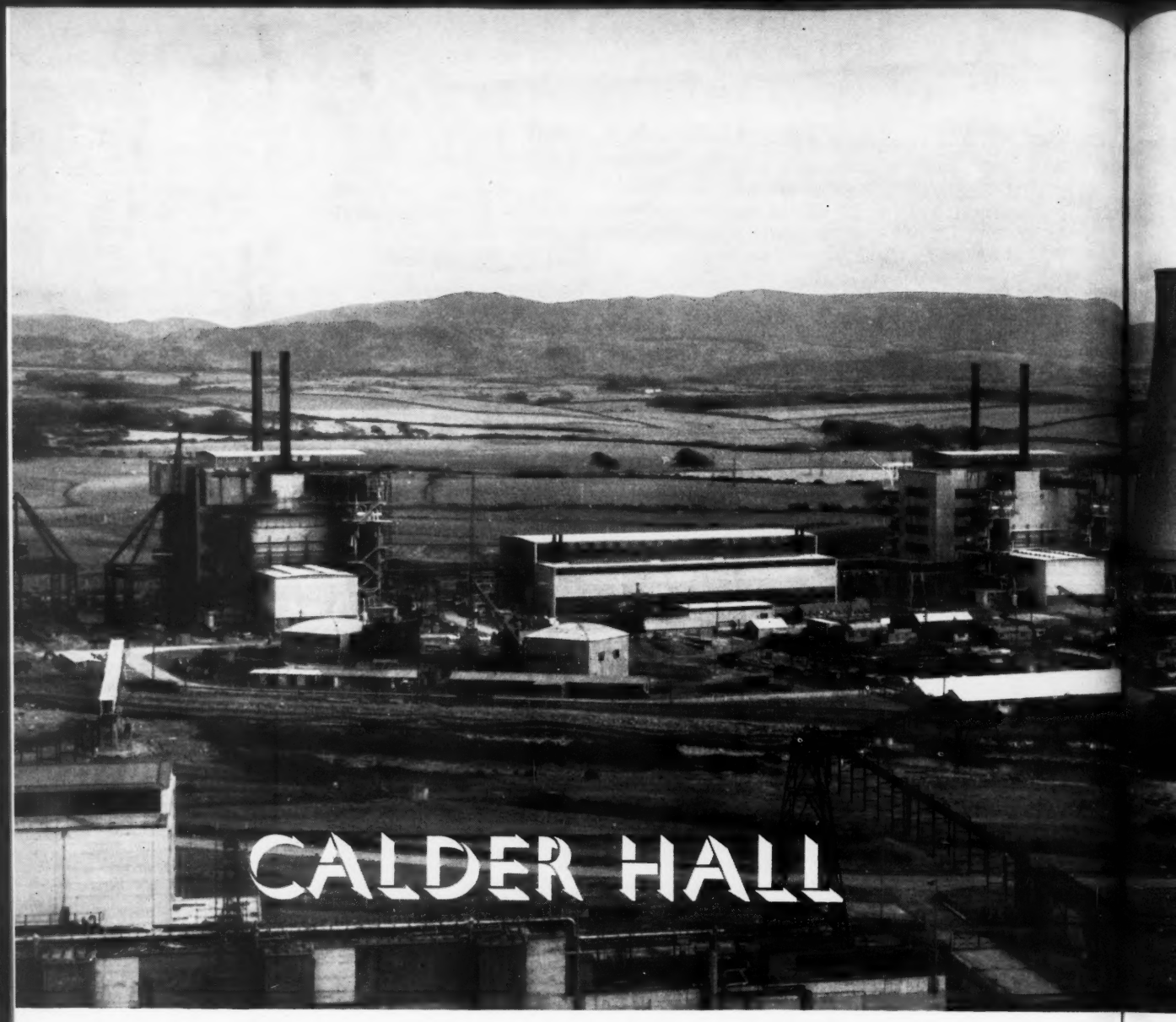
The U.K.A.E.A. for the past 18 months has been in the difficult position of being the design authority and consultant to the C.E.A. and the consortia, being required to give information to all groups impartially and yet to preserve normal commercial security between the groups. This is equivocal in the extreme and, although no suggestions of breach of faith or partiality have been breathed, it is hardly a satisfactory arrangement to perpetuate.

For a time no change is necessary, as contracts for both Chapel Cross and Dounreay are already placed. Designs for the first are identical to Calder Hall except some of the civil engineering detail, and the modifications to suit the new site are now finished, whilst a large part of the fast reactor is complete and other immediate developments at Dounreay require little further outside design effort and can be classed as straightforward contract constructional work. In the meantime, contracts will have been placed by the C.E.A. for the first power stations and work will proceed along normal established lines with the A.E.A. acting as consultants to the C.E.A., except for overriding power held by the A.E.A. in connecting with fuel-element manufacture and possibly graphite supply.

No complications will arise immediately if the stage 2 design is for a pilot-plant reactor rather than a prototype power reactor with the alternatives of a combined materials testing and high flux research or small power reactor, making borderline cases. If the decision is taken to go straight for a prototype power reactor, then the Calder Hall organization could be applied in the initiation of companies not previously connected with the atomic energy programme, but some change in the functions and relative positions of the A.E.A. and industry must be contemplated. Whilst there is little question that only by a powerful central control could Calder Hall have been completed so quickly, it must be acknowledged that the organizational system adopted is not suitable from a long-term standpoint and that, although the U.S. system has tended to spread and waste development effort in these early stages, some similar system must ultimately be adopted in the U.K.

THE SWITCH-ON

In a brief interview with the technical Press, the Northern Area Manager of the U.K.A.E.A. (I.G.) was emphatic that no power would be fed into the grid before October 17 in order to check the circuits. We are reminded of a much less important occasion not many years ago when a number of executives were gathered to witness the first testing of the standby generating equipment of a large works. Following the depression of the appropriate button, there was a momentary flash then the whole of the region went dark for three hours. The story is probably apocryphal but anyway—Good Luck, Mr. Davey.



CALDER HALL

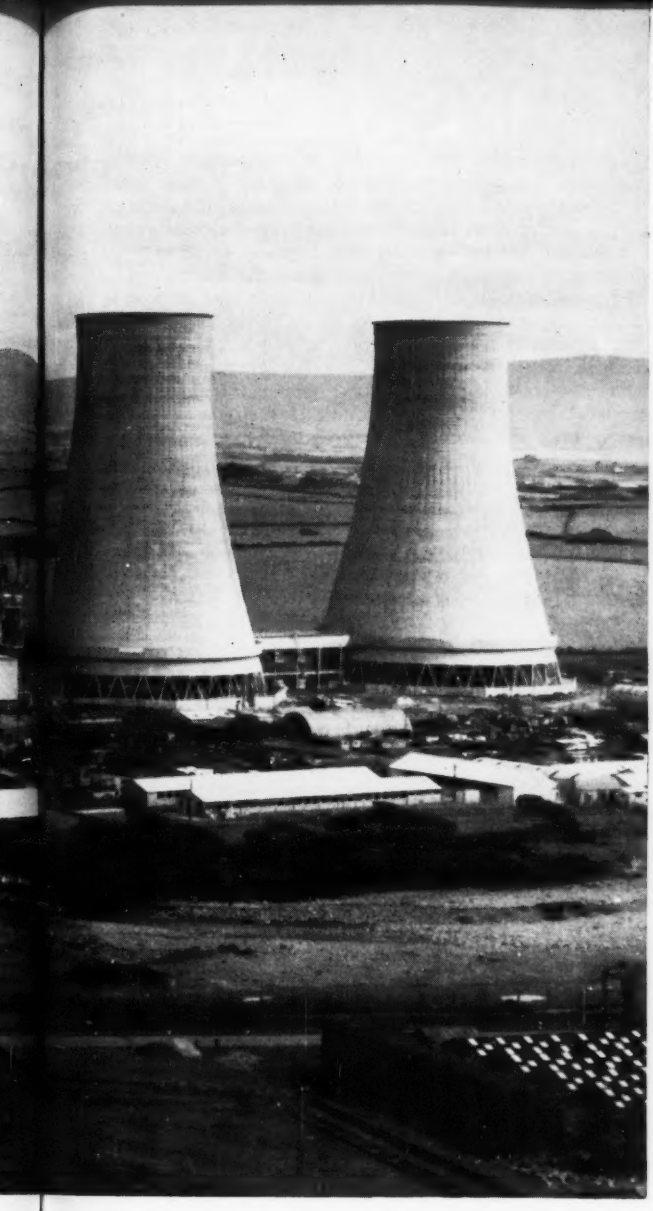
THE roots of the British graphite-moderated, gas-cooled power reactor go back to 1945. In that year, when the British Atomic Energy team, then working in Montreal, began to plan the research and development facilities which eventually formed Harwell, one of the first considerations was a reactor with which to conduct experimental work. The British reactor programme evolved into: first, the construction of research reactors and, secondly, the provision of pure fissile material, either plutonium or U 235.

The only possible fuel with which to start a nuclear energy programme is natural uranium and with it two moderators were at the time technically possible: heavy water and graphite. The team had then some design experience of the NRX heavy-water, natural-uranium reactor, but it was abundantly clear that heavy water—both expensive and slow in delivery—could not be contemplated for both the Canadian and the British efforts. On the other hand, a natural-uranium, graphite-moderated, air-cooled research reactor of some 2,000 kW heat output had already been operated successfully at Clinton in the U.S.A. No further discussion was necessary. Sufficient uranium and graphite for two reactors was obtained and their construction was begun at Harwell in 1946. The first was GLEEP, a testing reactor of, at most, 100 kW output and the second, BEPO, of 6,000-kW-designed heat output. One of the instructions to the designers of BEPO was that the greatest possible neutron flux facilities should be obtained with the least constructional complication and therefore in the least possible time; atmospheric air cooling was therefore essential.

The importance of the decisions, albeit dictated by necessity, cannot be over-emphasized; as it turned out, they laid the foundations for the British technique and experience in graphite-moderated, gas-cooled reactors which have led to Calder Hall and beyond.

The Department of Atomic Energy of the Ministry of Supply grew rapidly from 1946 onwards, the two main centres being the production organization at Risley under Sir Christopher Hinton and the research organization at Harwell under Sir John Cockcroft. During 1946 and 1947 much of the effort of both, together with a Ministry of Works team, was devoted to the design and construction of BEPO, which began operation on July 5, 1948.

Even in 1946, preliminary consideration had to be given to plutonium production and much thought was given to the best type of reactor for the purpose. At first the choice lay between water-cooled, graphite-moderated reactors similar



to the American production reactors at Hanford and graphite-moderated reactors cooled by gas under pressure, both of course, with natural uranium as fuel. The advantage of the first was the lower operating temperatures, apart from the knowledge that successful operation had been proved; the great disadvantage was the hazard arising from the increased reactivity consequent upon an accidental interruption of the cooling water supply. Against this, the gas-cooled version was "safe" and therefore could be built in more accessible regions, but it had to operate at higher temperatures and no experience of pressurized gas-cooled reactors had been obtained anywhere. Over all was the necessity for the rapid production of plutonium.

Fortunately, at this stage (1947), the virtues of finned fuel elements with gas cooling were recognized and it was decided that reactors cooled with atmospheric air could be made to yield plutonium at the required rate, and in a shorter time than with any other system. In fact, a "super BEPO" became possible, and the decision was taken to build two reactors on this principle at Windscale.

The development of gas-cooled, graphite-moderated reactors had progressed to the point where power output and fuel ratings were of the same order as those necessary in large power reactors; but, for power generation, two factors had yet to be much improved upon: the operating temperature and the power absorbed in circulating the gas coolant.

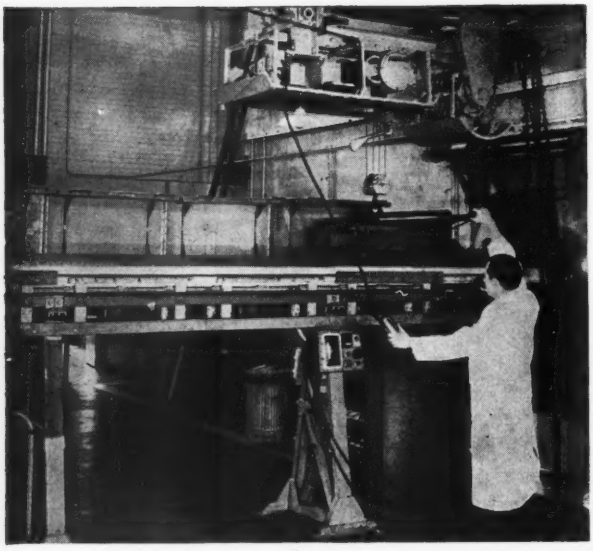
Ever since 1945 thought had been given periodically to the practicability of power generation by way of graphite-moderated, gas-cooled reactors, in Great Britain. That such a project was technically possible was not doubted; the prime uncertainty was one of economics. Would not a natural-uranium, gas-cooled system of large size and of modest thermal efficiency, contained in an enormous pressure vessel of unknown complexity, be much too expensive? What was the real price of natural uranium and how long would a fuel element last at the temperatures and ratings necessary for economic power? These were the questions which bedevilled thought on the problem up to 1950. In that year sufficient information and experience became available for an economic study of some conviction to be carried out. Within a few months it became clear that the next step in our gas-cooled development should be taken without further delay; a natural-uranium, gas-cooled reactor enclosed in a pressure vessel was practicable, and held out real hope of electrical power at a penny or less per unit.

Design

Very briefly, the problem resolved into the enclosure of a Windscale-type reactor in a pressure vessel, raising the temperature of operation, using a coolant gas which would not react unduly with the graphite at the increased temperature and the provision of heat exchangers in the primary cooling-gas circuit to generate steam.

Engineering design is an art as well as a science. It is always necessary when designing a plant to achieve a balance between the conflicting claims of the individual sciences. This is especially the case with a complex plant such as a nuclear power reactor, where the rival claims of nuclear physics, chemistry, metallurgy, mechanical strength and reliability and structural feasibility all have to be reconciled. The net power output of a gas-cooled reactor depends, for instance, on the diameter of the core, the gas pressure, the degree of flattening, the permissible fuel-element temperature, the choice of coolant gas and the design of the gas circuit. With a specified limit for the fuel-element temperature the power output may be increased, other things being equal, by increasing the core diameter and the gas pressure. Both these changes, however, accentuate the problem of the design of the pressure vessel. If there is a definite limit to the thickness of steel plate that can be handled for site welding operations, then a limit will be set to the product of working pressure and pressure-vessel diameter. The design engineer must decide where to strike a reasonable balance, bearing in mind all the time the limitations set by the nuclear physics of the system on the permissible range of core diameter.

One of the most striking differences between the Windscale and the Calder reactor designs is that in the former the fuel channels are horizontal and in the latter vertical. Prior to the Calder design, all graphite-moderated reactors in this country and in the U.S.A. had horizontal fuel channels, because this arrangement permits easy support for the heavy fuel elements and, in the absence of a pressure shell, fairly simple arrangements for charging and discharging the fuel. One of the primary reasons for the change concerns the support of the 1,000-ton cylinder of graphite. In previous graphite reactors there had been room to provide a substantial flat platform or series of wide steps supported directly from the foundations upon which to erect the graphite structure. It must be remembered that this is composed of thousands of blocks, which must be installed in such a way that thermal and other movements do not cause the fuel and control-rod passages to be obstructed. Within the necessarily restricted diameter of a steel pressure vessel, support in this manner is not easy and, indeed, may not be possible without a big increase in the vessel's diameter. (In the French G2



The first British reactor GLEEP, showing the materials-checking train. The assembly, which became critical early in 1947, has a maximum heat rating of 100 kW.

and G3 reactors, where the channels are horizontal, the pressure vessel is of concrete.)

The problem becomes easier if the structure is supported upon one of the ends of the cylinder, the base structure then being a circular platform or "diagrid" within the pressure vessel and supported from the foundations through the perimeter of the vessel. This arrangement has been developed for Calder Hall and several other advantages become apparent. The control rods, which are best aligned parallel to the fuel rods to maintain a uniform heat distribution through the pile, may then move in a vertical direction and the whole layout of the plant, with vertical heat exchangers becomes neat and compact. However, a price has to be paid for these advantages, and the vertical arrangement is possible only if the major problems of fuel-element support and fuel changing can be solved.

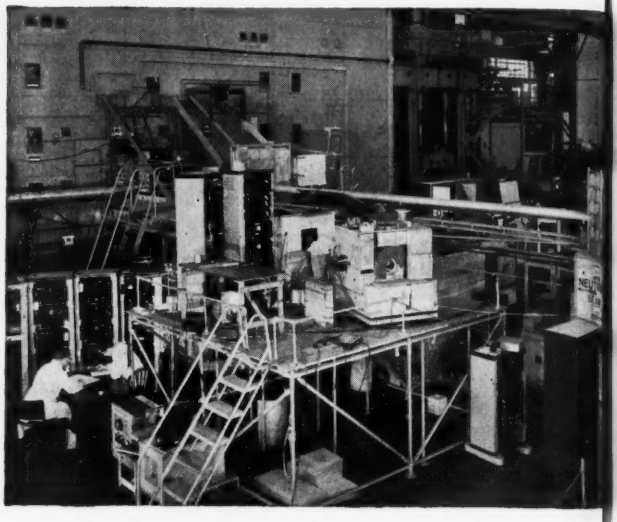
Arrangements for supporting the fuel elements in the vertical channels must take into account the necessity for positively locating each fuel cartridge centrally in the channel, so that cooling is maintained equally around the circumference and the structural strength limitations (which increase with increasing temperature) imposed by the weight of the elements above.

The central location is achieved by spiders at each end of the cartridges. These abut against the graphite channel walls and yet permit axial movement of the cartridge during fuel changing. The problem of structural strength of the cartridges is alleviated partly by choice of the cartridge-canning material, and partly by arranging for the cooling gas to flow upwards through the reactor. The position of greatest stress in the cartridges is also the position of lowest temperature, thus increasing their strength.

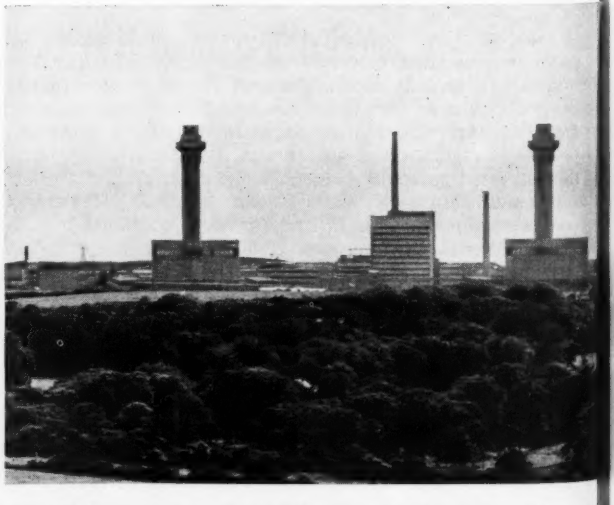
The decision to make the gas flow upwards in the reactor has other important advantages. For example, the structure supporting the graphite load and the main supporting arrangements of the reactor are at the cooler end. Also, since the gas flows downwards through the heat exchangers, the gas circulators, which must, from power consumption considerations, be located at the coolest part of the circuit, may be supported at ground level without extra ducting.

Another notable feature of the design is the provision of four heat exchangers arranged symmetrically around the reactor. Common prudence demands the division of the heat exchanger facility into a number of independent circuits. In addition, the system permits the necessarily large flow area for the gas to be divided into four paths, so that the diameter of the duct-entries at top and bottom of the reactor pressure vessel are reduced and so that thermal expansions in the duct pipes radiate symmetrically from the reactor. Further, the pressure vessels of the heat exchangers are reduced in size sufficiently to allow sections to be manufactured in the factory and transported to the site by road.

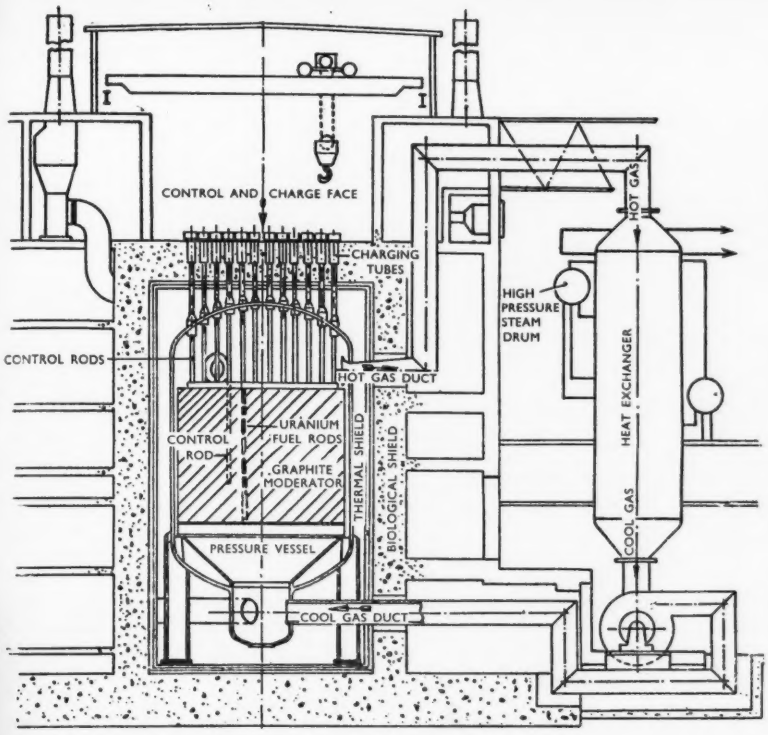
Turning to the fuel-handling system required to serve channels on an 8-in. pitch, if a hole had been made in the upper pressure vessel head opposite each channel it would have been extremely difficult to ensure enough ligament strength between the holes. The solution here was to provide only one hole in the pressure vessel head to every 16 fuel channels, the charging machine being designed so that any hole in a group could be served through this one orifice. The same holes also provide access to the control rods.



The experimental face of BEPO, the main British research reactor de to run at 6 MW. Most of the fundamental research on the gas-c graphite-moderated type has been on this reactor.



The Windscale reactors and plutonium production plant, half a mile the Cumberland coast. The Calder Hall station adjoins it on the (left) side.



MAIN FEATURES OF THE CALDER HALL PLANT

Vertical arrangement of fuel channels.
Vertical control rods.
Vertical cylindrical pressure vessel.
One charge tube to 16 fuel channels.
Carbon dioxide flows up through reactor.
Four heat-exchanger circuits.
Down flow through heat exchangers.
Dual-pressure steam cycle.
Operated at constant heat output.

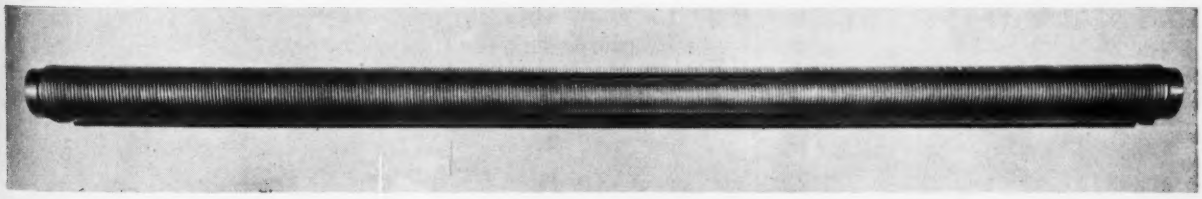
In choosing the coolant gas, the design engineer had to take account of compatibility with the materials of the fuel elements and with the graphite moderator the problems of heat transfer and the heat capacity of the gas stream. Also, consideration had to be given to the design of the gas compressors or circulators, and last, but not least, the cost and availability of different coolants. From many points of view, helium would be an excellent technical choice as the coolant for a gas-cooled reactor. Unfortunately, the high cost and limited availability of helium would exclude its use in any country other than the United States. Another interesting technical possibility would be the use of hydrogen which, in view of its excellent heat capacity, would enable the pumping power to be reduced very considerably. Many problems remain to be solved particularly in the choice of materials, however, before hydrogen could be considered as a practical possibility. In the meantime carbon dioxide, which is reasonably good from a compatibility point of view and reasonably cheap, was chosen.

It has already been mentioned that the Calder Hall plant is a plutonium-producing rather than a power-producing plant. That is to say that the design has been optimized to give plutonium production at the most economic rate as well as electric power at the lowest possible cost. One result of this is that, to achieve a high heat output and therefore also the largest practicable rate of plutonium production, the return temperature of the gas is somewhat lower than it would have been had the plant been designed exclusively for electricity generation. For this reason, the boiler pressures in the dual-pressure steam cycle are relatively low.

The decision to use a dual-pressure cycle is a natural consequence of the wide temperature range between gas inlet and gas outlet temperatures, and this, in turn, is a direct consequence of the limits set by the permissible pumping power and by the heat capacity of the gas stream. Gas-cooled reactors designed exclusively for power station duties will almost certainly retain this feature of the dual-pressure or even a multi-pressure cycle, although the gas inlet temperatures will be higher and the steam pressures will be correspondingly greater.

Another peculiarity of the Calder Hall type of plant is that it will be operated as far as possible at an absolutely steady level of heat generation, to maintain the highest possible rate of plutonium production. In the event, however, of a sudden rejection of load on the electricity system, it is desirable to avoid a sudden reduction of heat output from the reactors and for this reason a dump-condenser system of large capacity has been included in the steam plant. Future civil power station reactors, although being operated at a high load factor for economic reasons, will probably be controlled in a different manner and, to some extent at least, they will be able to follow load variations on the system.

The Calder Hall plant has formed the starting point of the design of the first civil power station reactors for the Central Electricity Authority and for the South of Scotland Electricity Board. One of the most interesting developments of the past year has been the growing confidence among the design engineers in the leading engineering firms concerned in these projects that the gas-cooled reactor has immense possibilities of development, particularly in the largest sizes. Many of those who have studied the technical potentialities of these basic designs are convinced that the gas-cooled reactor will become established as the normal type of power plant for large base-load stations for many years to come.



A fuel element with the end spiders removed. Enclosing a natural-uranium slug in a helium atmosphere, the magnesium alloy tube is turned from the solid with a single-start helical fin of ½-in. pitch. Transverse fins have superior heat-transfer properties under the reactor conditions than have longitudinal ones.

Civil Engineering Aspects

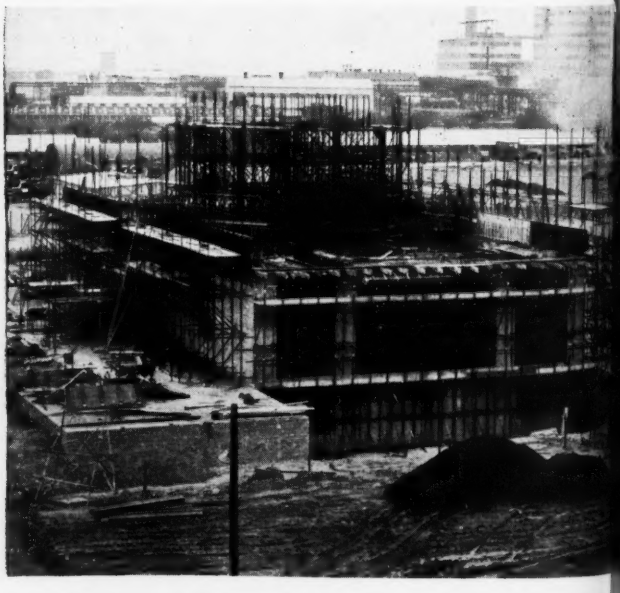
THE building and civil engineering contract for Calder Hall "A" was placed with Taylor Woodrow Ltd. on July 22, 1953, and work began on August 4. Worth nearly £2½ million, the contract consisted of two reactor buildings 120 ft. high; two cooling towers 300 ft. high and 200 ft. in diameter; the turbine hall; and ancillary buildings and services, including road systems. Within 12 months, work on the first of the two reactors was completed, and all building work on the remainder of station "A" will be finished by November, whilst Calder Hall "B", identical to "A", will be about 60% complete.

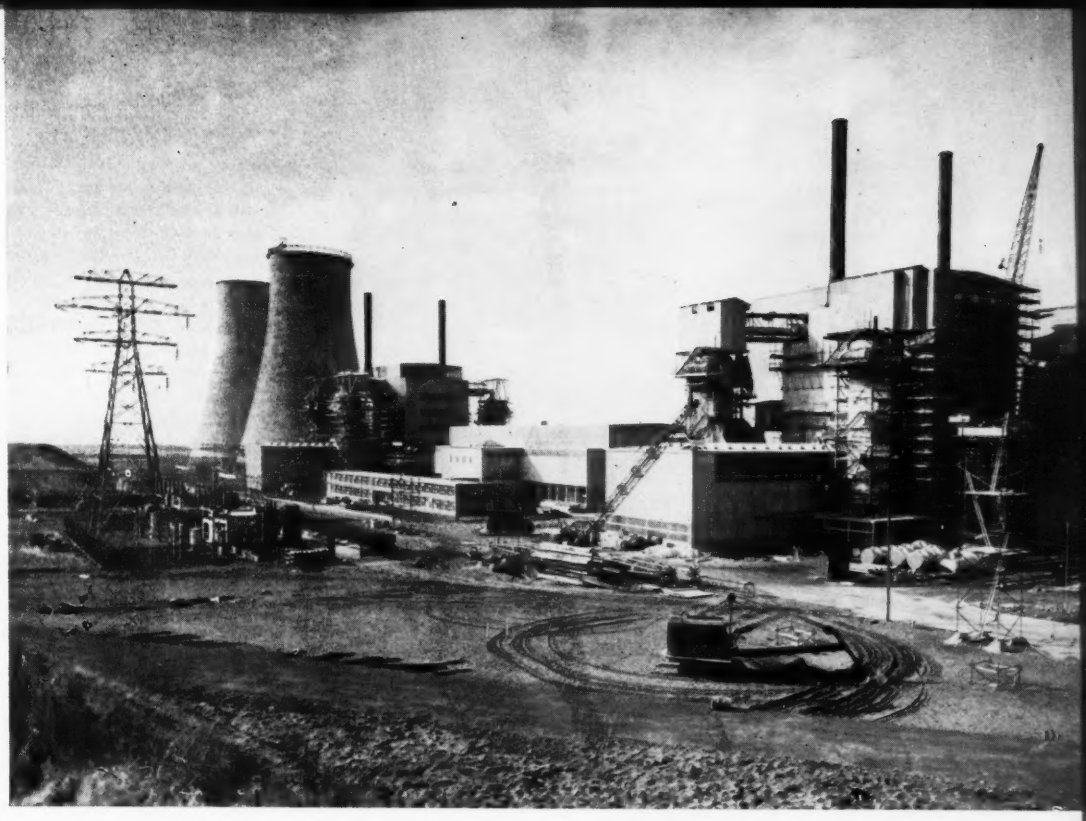
Because of the concentrated and heavy weight of the reactors, special arrangements had to be made for the foundations. Each reactor weighs 33,000 tons, imposing a pressure on the substrata of between 2½ and 2¾ tons/ft.^{2} Fortunately, at Calder there is sandstone rock at depths varying from 60 to 100 ft. Overlying this rock is a glacial moraine containing little silt, but clay lenses at intervals. Very full soil mechanics reports were obtained on the substrata and graphs of actual settlement over a period of about two years were available. Estimates of probable settlement were, of course, based on the clay lenses, but there was every indication that settlement would be even. Each foundation raft is 130 ft. long, 107 ft. wide and 11 ft. thick, and contains 5,600 cu. yd. of concrete and 273 tons of ⅞ to 1⅛-in.-dia. steel reinforcing rods. The rafts were constructed in four lifts, each divided into 21 bays, the placing being by alternate bays at three-day intervals. Two 7-ton derricks, running on tracks along each side of the excavation, were used for placing the concrete and reinforcement. From the civil engineering viewpoint, the construction of the biological shield is the most interesting feature of the work. First, exacting requirements in respect of high density and uniformity of concrete had to be met, and great care taken in the placing of the concrete in confined spaces around the very large number of charging and other tubes passing through the shield. Secondly, extremely close tolerances were demanded, within ± 1/10 in. on both vertical and plan true dimensions.

In order to meet the specification of a density not less than 150 lb./ft.^{3}, an appropriate aggregate had to be found: the most suitable obtainable within a reasonable distance was Northumberland whinstone which has a specific gravity of 2.9, thus giving a concrete density of 162 lb./ft.^{3} The cost of transport added about £1 per cu. yd. of concrete, equivalent to a 15% increase. The ratio of whinstone used was 6.3:1, this being changed later to 7.5:1. A very dry mix was specified, the water-cement ratio being 0.5:1, and a detergent, Lissapol N, used as a wetting agent. The crushing strength of the concrete was specified 3,000 lb./in.^{2} minimum, 6-in. test cubes being taken from every pour.

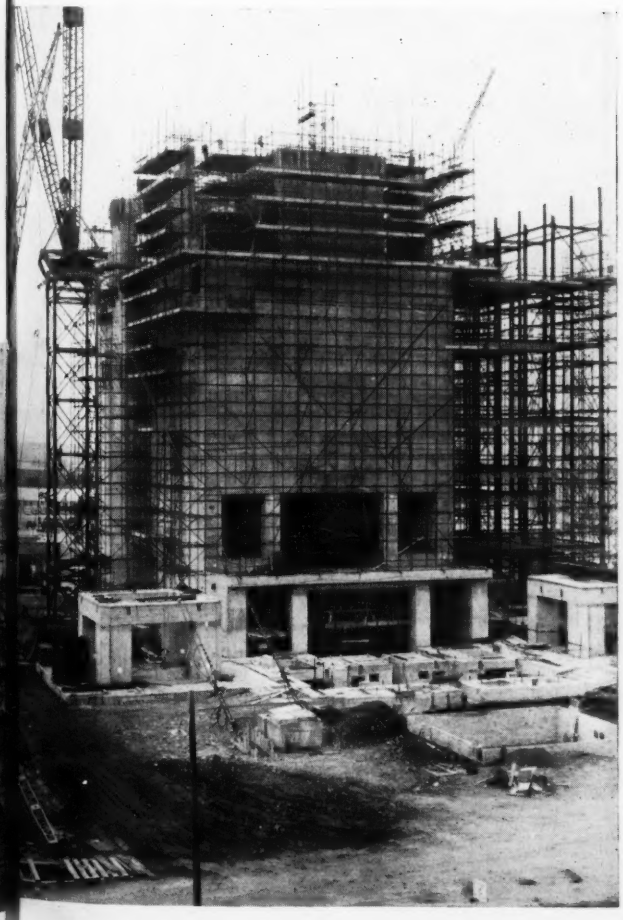
Mixing was carried out in two 1-cu.-yd. Stothert and Pitt batching mixers fed by 19-RB excavators and a central

(Left, below and right). Three views of a reactor building under construction. The two photographs on this page show the central spider and octagonal framework for the shuttering of the biological shield.





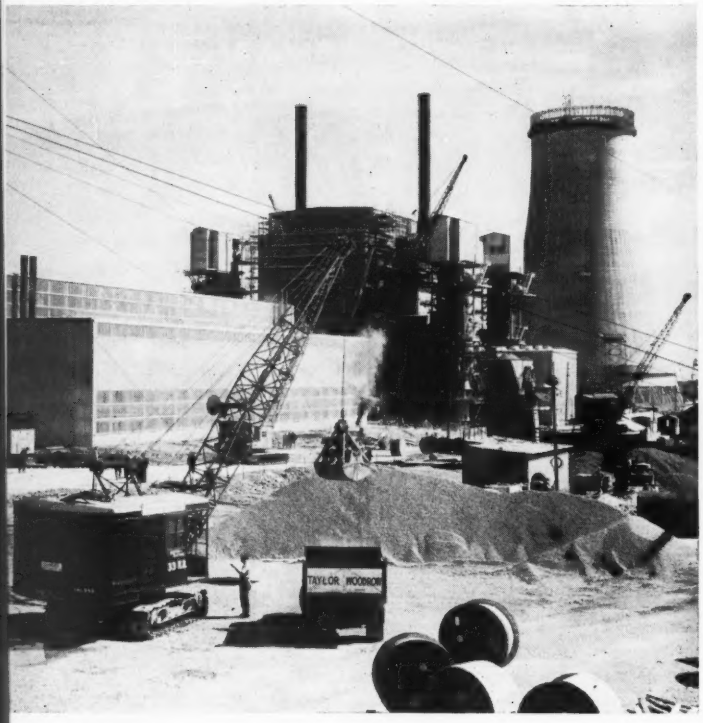
Calder Hall "A" at March, 1956, shows the civil engineering work very near completion.



airflow bulk cement handling plant. One mixer was used for the whinstone concrete only, the other serving the remainder of the concrete requirements. During cold weather, the aggregate and water were steam heated and calcium chloride was added. Because every precaution had to be taken against the formation of voids, no pumping or chuting of the mix was allowed. The concrete for the shield was placed by 2-cu.-yd. discharge skips. Immersion vibrators were employed to remove air entrainment, petrol-driven A.C.E. Humdinger and C.P.T. air-driven types being used.

The octagonal biological shield is 90 ft. high, 60 ft. across parallel faces and 7 ft. thick. The building of a structure of these dimensions to the specified tolerances of only ± 1/10 in. required much careful initial preparation and continuous checking as the work proceeded. Accuracy was achieved by erecting a central spider of angle iron in the form of 6-ft. cubes forming a rigid and accurately dimensioned structure providing the support for a 90-ft. plumb-line from which all measurements were taken. To this spider, designed by C. Parry, was fixed an octagonal inner template. The shuttering was 2-in. t. and g. panels 10 ft. × 4 ft. 6in. with Parry-type clamps bolted to nuts embedded in the concrete. The concrete was poured in 20 lifts of 4 ft. 6 in. in alternate bays, with a three-day delay between pouring of adjacent bays, and so arranged that the corner bays were leading by one or two lifts. The bays were wedge-shaped with vertical serrated or stepped adjacent faces. All joints were carefully hacked before pouring, the upper surfaces being hand picked and vertical faces hacked by air tools.

Provision had to be made for various service holes in the sides of the shield, these having steel sleeves inserted before pouring. An access hole, 6 ft. × 4 ft. 6 in., was also left in the base of one wall: this stepped-face section connected with the discharge chute and coffin transporter track and was blocked up when all work inside the shield had been completed. Provision was also made for the air cooling of the shields and pressure vessel, ring ducts being incorporated

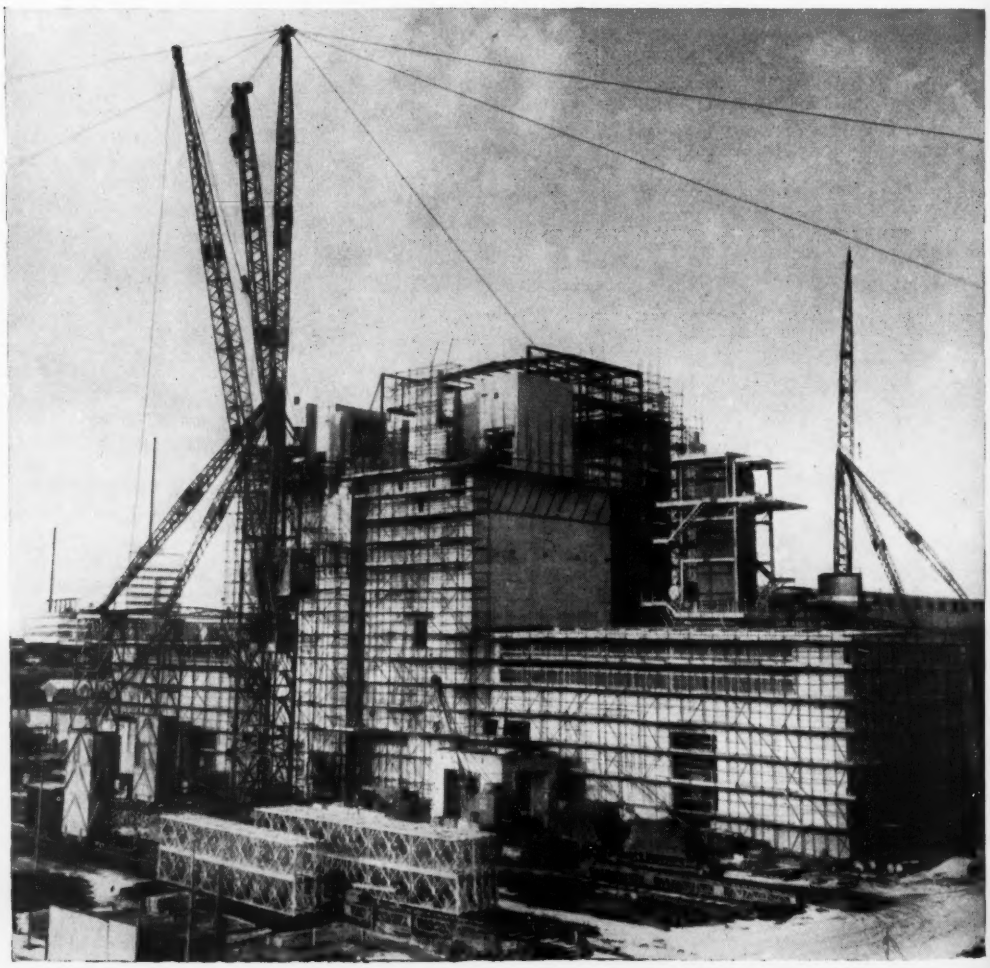


Aggregate store and concrete weigh-batching and mixing plant set up behind the turbine hall of Calder Hall "A" station.

in the concrete; air is circulated, for example, between the biological and thermal shields. This system is supplied by Howden blowers, the air being exhausted to atmosphere through stacks at 200 ft.

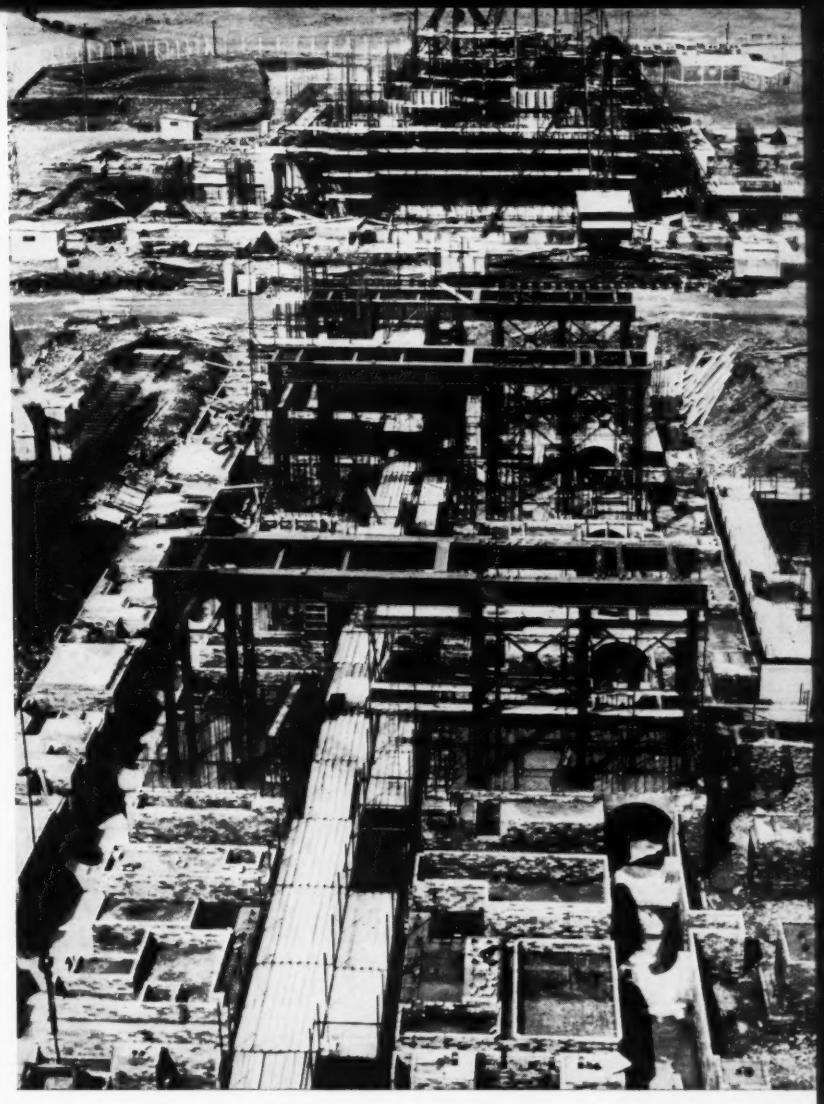
The gap between the thermal and biological shields is 6 in. The thermal shield comprises about 500 plates of 6-in. thick steel each weighing 3 tons, hot-rolled at the Sheffield works of the English Steel Corporation Ltd. The plates are not joined together in any way, simply resting on top of one another and supported by vertical channel soldiers. These channel sections, of which there are 16, are disposed at each of the eight corners of the octagon and midway on each face. They are made up of 6-in. plate with the addition of thinner welded steel plates to form a channel in which the shield plates can slide. The channels are bolted at intervals to the concrete biological shield. Provision, necessitating the use of shaped plates, had to be made for various services through the shields to the pressure vessel. The floor plates were laid on horizontal channels and incorporated mountings for the inverted "A" frames supporting the pressure vessel: this is described elsewhere. Matthew Hall and Co. Ltd. carried out the installation of the thermal shield and various pipework through the shields.

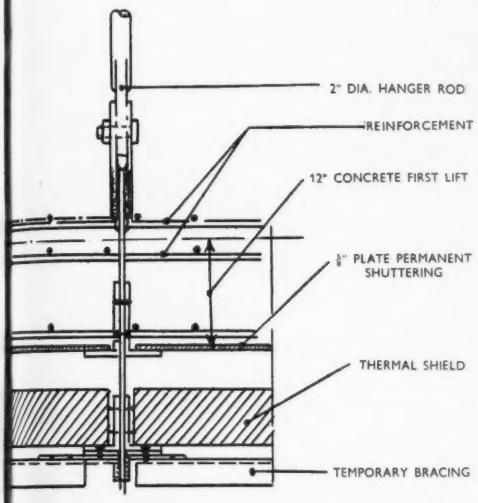
Upon completion of the walls of the biological and thermal shields, the pressure vessel was assembled, the graphite loaded, and control and charge tube sleeves fitted in place before the top thermal and biological shields could be placed. Although it might appear to have been more practical to have built the biological shield around the pressure vessel, the reverse procedure was adopted to save time, as it was realized



This view of a reactor building under construction shows the 150-ton capacity, 200-ft. high derrick and, in the left foreground, sections of the Bailey double-double bridging used to support the top thermal shielding and shuttering for the 8-ft.-thick concrete roof of the biological shield.

(Right) Foundations of the turbine hall and, in the background, one of the reactors.





Details of one of the stirrups, suspended from Bailey bridging, used to support the top thermal shield and shuttering for the concrete roof.

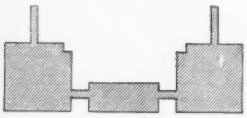
that possibly up to a year's development work would be necessary on the pressure vessel and other components. In the event, this decision was justified, although some tricky lifting problems were posed. Before placing the 8-ft.-thick concrete roof of the shield, a series of double-double Bailey bridge girders was erected across the top from which hung a number of 2-in. mild steel rods terminating in stirrups for the support of the top thermal shield and the shuttering for the concrete.

The lower ends of the stirrups were interconnected by welded steel tees on which the top thermal shield plating rests. The tees are not rigidly connected to the hangers, slotted holes and dowels being used to allow for thermal expansion. Steel angles, drilled to take the lateral reinforcement rods, were then rigidly fixed to the hangers at a higher level. Mild steel plates, $\frac{3}{8}$ in. thick, were laid on these angles and all welded together to form a base for the concrete. Collar plates were welded on round all control and charge tube sleeves passing through. These sleeves were held in position by extensions from the Bailey girders.

Because it was necessary that the underside of the roof should be as nearly level as possible, the plane of the shutter was precambered by adjustment of the nuts at the top of the hanger rods. This initial camber was $\frac{3}{8}$ in. The casting was carried out in four lifts, extreme care having to be taken in compacting because of the large number of through tubes and thermocouples embedded in the concrete. After the third lift, the stirrup rods were cut off at the top face just above a mild-steel plate welded to each rod, the Bailey bridge removed and the final lift poured. The $\frac{3}{8}$-in. plate had to bear the load of the first lift only, comprising 12 in. of concrete. This concrete layer then formed the permanent shuttering for the remaining three lifts of 2 ft. 4 in. each.

The other civil engineering work, such as the reactor building, cooling towers and turbine hall group, was straightforward. The main turbine hall has a structural steel framework with asbestos-cement cladding and patent glazing, the roof being of steel decking covered with three layers of bitumen felt. The four identical turbine blocks were concreted in one pour each. The steam end of the block comprised 125 cu. yd. of concrete and the alternator end 175 cu. yd., on surface areas of 225 sq. yd. and 415 sq. yd. respectively. To carry out the pour in one lift rather special care had to be taken with the design and fabrication of the shuttering. The concrete was fed into hoppers located above the site, with flexible hoses attached to the hoppers so that the pour could be done evenly and compaction carried out without difficulty. Telephone communication was set up between the various working levels and the central control.

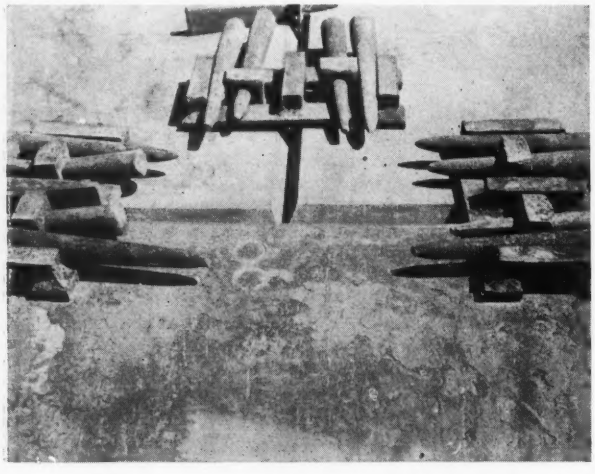
The 300-ft.-high, 200-ft.-diameter cooling towers of conventional design were erected in 3-ft. lifts at a rate of one lift a day, the work being carried out from an internal scaffolding of prefabricated steel construction. The control of circulating water through the towers is effected by four penstocks, 6 ft. wide and 4 ft. wide, in the ducts leading to the ponds. These are hand-operated, the weight of the door being carried on heavy ball thrust bearings: as there is no appreciable head of water, a two-speed gear is not required. Sludge can be sluiced out by four 12-in. disc valves and two 12-in. flat outlet valves in the culverts and ponds. Smaller valves control the warm water circuit for de-icing. The penstocks and valves were made by Ham, Baker and Co. Ltd.



Reactor Pressure Vessel

WHESSOE LTD., of Darlington, were appointed by the U.K.A.E.A. to be responsible for the pressure vessels enclosing the reactors. In spite of their long experience with pressure vessels, dating from the early days of the gas industry, there were several points about these particular units which necessitated a considerable amount of design effort before satisfactory solutions were obtained to the many problems superimposed on the fundamental requirement of a large vessel intended to withstand internal pressure. First and foremost was the question of support. The vessel's own weight was considerable, so was that of the mass of graphite to be contained. Once installed, there was little opportunity for inspection (although visual inspection will be carried out by television, and removable test samples will provide some information) and practically no possibility of maintenance. In addition, the vessels had to be built to dimensional tolerances which would almost be considered microscopic for this class of work; they had to maintain accurate alignment of internal and external features over a wide temperature range. Furthermore, they had to be built on site, without the benefit of factory conditions.

The sum total of these conditions, formidable enough for a plain shell, was further complicated by the necessity of providing a large number of apertures in the shell, varying from mere nozzles to holes up to 12 ft. in diameter, to which it was not possible to apply conventional methods of compensation.



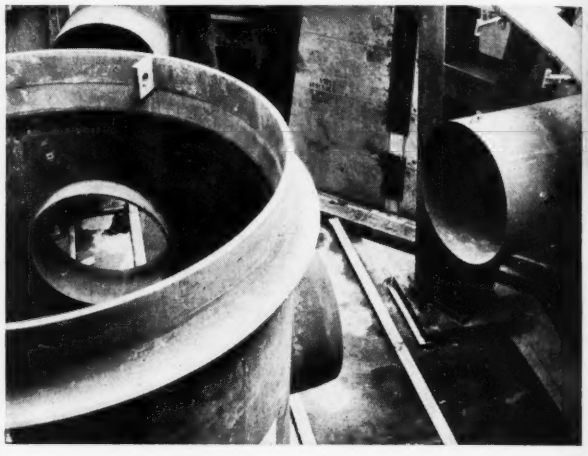
Close-up of lower dome plates ready for welding.

Only a short time before the design of this vessel was undertaken, a contract had been placed for another unusual project. This was the vertical spinning tunnel for the N.A.E. near Bedford, and the experience gained during the construction of this was to prove invaluable in the present application, strain gauge tests on this vessel under pressure, yielding valuable design data, particularly regarding the stress distribution around large holes.

One of the limiting features was the maximum thickness of plate which it was considered possible to weld on site, bearing in mind that all welds were to be Class 1 standard. This thickness was fixed at 2 in. and, for a dome-ended cylindrical vessel of the dimensions envisaged, the working pressure was about 100 lb./sq. in. The requirements of field welding dictated a ductile mild steel with a good notch value at low temperatures, and that finally selected was an aluminium-killed, high-manganese steel, manufactured under the trade name of "Lowtem" (Consett Iron Co. Ltd.).

General Design

The vessel, which has a total volume of 37,500 cu. ft., takes the form of a vertical cylinder 37 ft. inside diameter and 71 ft. 6 in. high, with domed ends of ellipsoidal form, the lower end having an auxiliary dome, some 12 ft. in diameter, to act as an inlet manifold for the coolant. It is arranged to stand on a number of vertical legs of "A" frame design, equally spaced round the periphery so as to allow radial movement during expansion and contraction, maintaining the centre line fixed in space. This, it was considered, would not be possible with a conventional skirt ring support.



Inlet manifold, showing construction of strengthening ring.

There are ten "A" frames, loosely bolted on to brackets on the pressure vessel and to the thermal shield foundations. The three contact surfaces of each "A" frame are radiused, thus enabling expansion to be accommodated by a rolling motion.

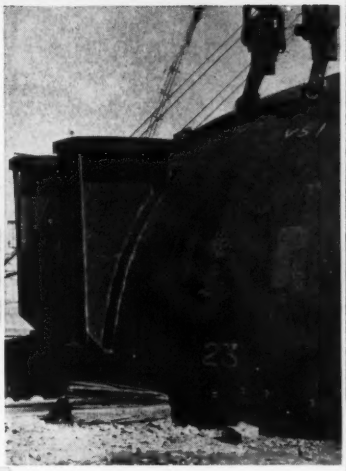
The design also provided for the internal load of the reactor core, amounting to some 1,000 tons, to be supported so that its weight did not add to the pressure stresses in the shell, but was directly transmitted to the external supports. To this end, the weight of the core was taken by what has been called a "diagrid",* a structure of crossed I beam members, there being eight beams in each of two directions surrounded by an I-section ring. The computer at the N.P.L. was pressed into service for solution of the design equations. This circular grid, which weighs 63 tons, is supported at the periphery on brackets which are welded to the shell exactly opposite the "A" frame brackets.

Before construction began exhaustive physical tests were carried out on samples of the plate, tests including an examination for corrosion in the presence of hot CO_2. In addition, every plate was subjected to 100% examination using ultrasonic methods, for lamination or slag inclusions.

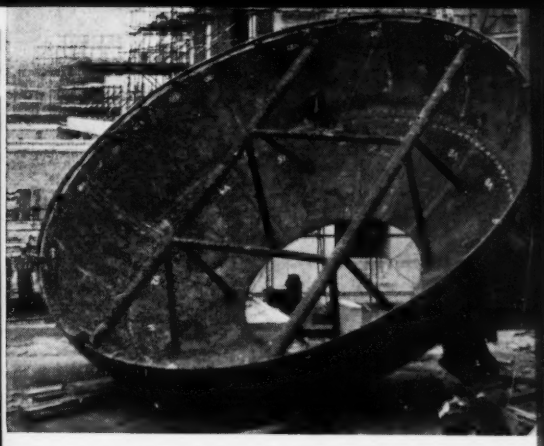
*This name was applied, it is said, due to a missing full stop in a drawing which read "35 ft. dia grid . . .".

Illustrations courtesy Ace Distributors Ltd.

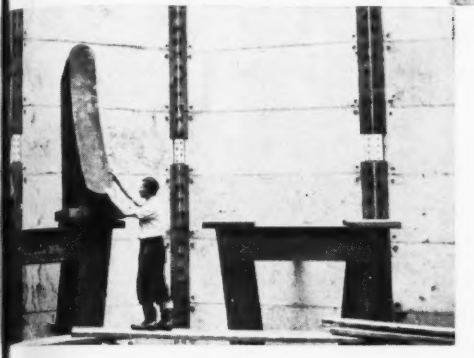
Lower dome during fabrication.



"A"-frame bracket welded in position.

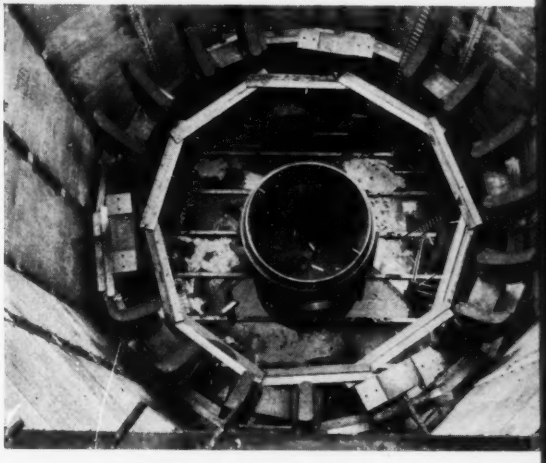


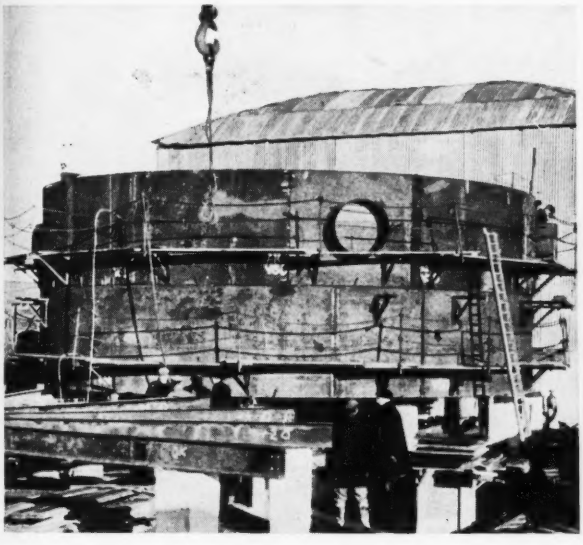
Internal stiffening for dome during lifting.



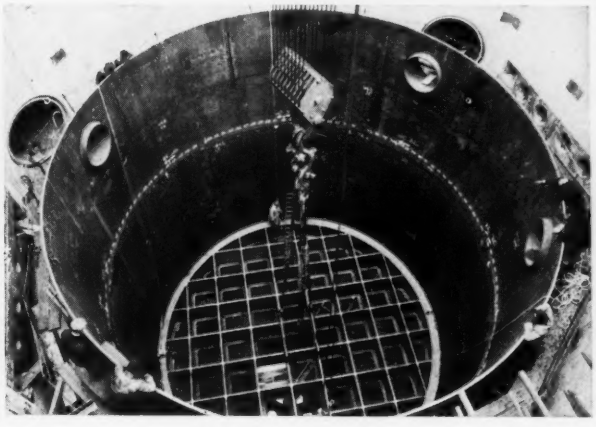
(Left) Detail of brackets and "A" frame.

(Right) Bottom of reactor enclosure before placing lower dome.





Upper cylindrical section of vessel with gas outlet stubs.



Placing diagrid into position.

During fabrication, frequent tests were carried out on batch samples of plate to ensure that there was no variation from the specification laid down.

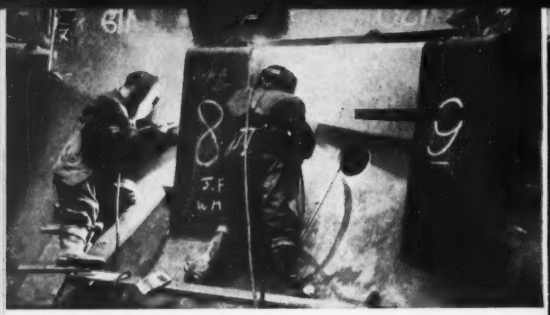
Construction

Factory operations included cutting to size, edge preparation and rolling to radius in the case of the shell plates, and hot-pressing in the case of the sections of the domed ends, each of which comprised 31 plates.

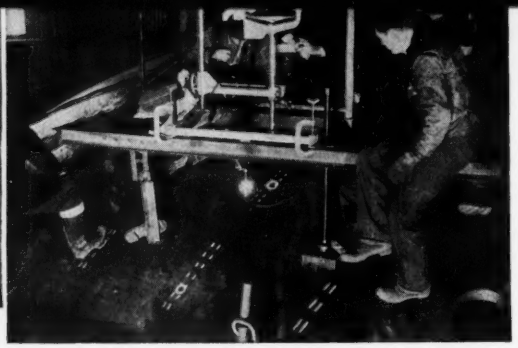
Fabrication of the lower dome took place on site in an upside-down position. The 16 knuckle plates and 15 petal plates of which it is composed were first assembled in their correct positions to give a clearance of $\frac{3}{16}$ in. for running the welds, being temporarily secured first by pegs and clips and then by tack welding, before the main runs were commenced. On completion of this portion, resulting in an ellipsoidal dome with a 12-ft. central hole, a temporary stiffening framework was welded inside to prevent distortion during handling, and three of the "A" frame brackets were welded on. The unit was then inverted and placed into position.

The inlet manifold for the coolant is a small-diameter deep-dome unit which is located at the centre of the lower end and carries stubs for the four gas ducts. Junction between the manifold and the main vessel is by means of a forged steel ring which is welded around the top of the manifold and provides compensation for the large hole in the lower dome of the pressure vessel.

The stubs for taking the ducts at the top and bottom of the vessel have a wall thickness of 4 in. where they pass through the plates, and are swaged down to 2 in. where they join the ducts. The welding of the stubs into the thick plates occupied a total time for each joint of 26½ hours.



Welding diagrid brackets inside vessel.



Flame - trepanning holes in top dome for nozzles.

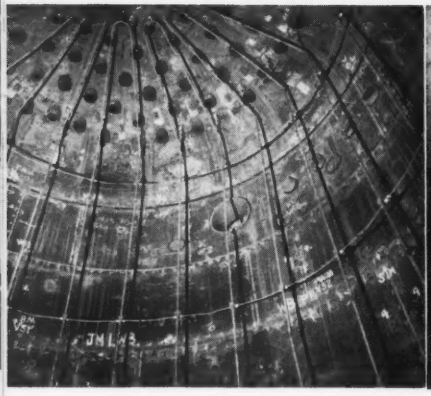
(Left) Welding nozzles in top dome.

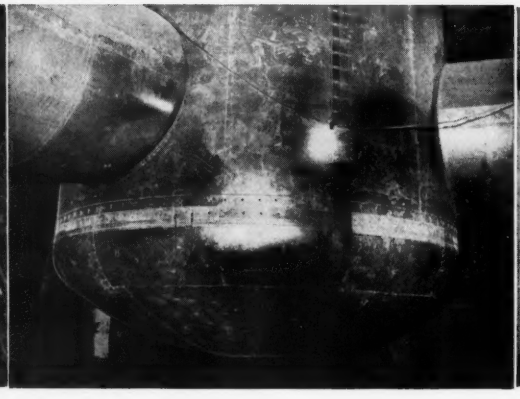
(Right) Drilling pilot holes for charge tubes.

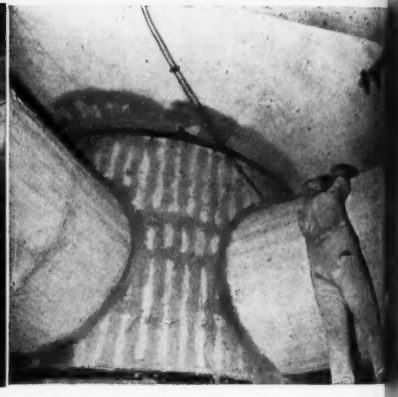
(Below, left) Inside vessel, showing heating conductors in place for stress-relieving.

(Below, centre) Gas-inlet manifold being lagged.

(Below, right) Gas - inlet manifold lagged and cleaded.







The manifold with its stubs was set at the bottom of the biological shield structure and when the dome had been lowered on to the "A" frames it was jacked up and welded.

The lower vertical section, three plates in height, was next placed and welded, followed by the upper section containing the four outlets for the CO_2 ducts. Compensation for these holes was achieved by the use of special "hole plates" made by the English Steel Corporation by a combination of forging and machining, with a cross-section swelling from 2 in. at the edges to 4 in. at the hole.

The top dome was finally placed in position and welded, after the insertion of the grid and the plates for supporting the core. The stub nozzles for the reactor charge tubes and control rods had been welded in place before lifting.

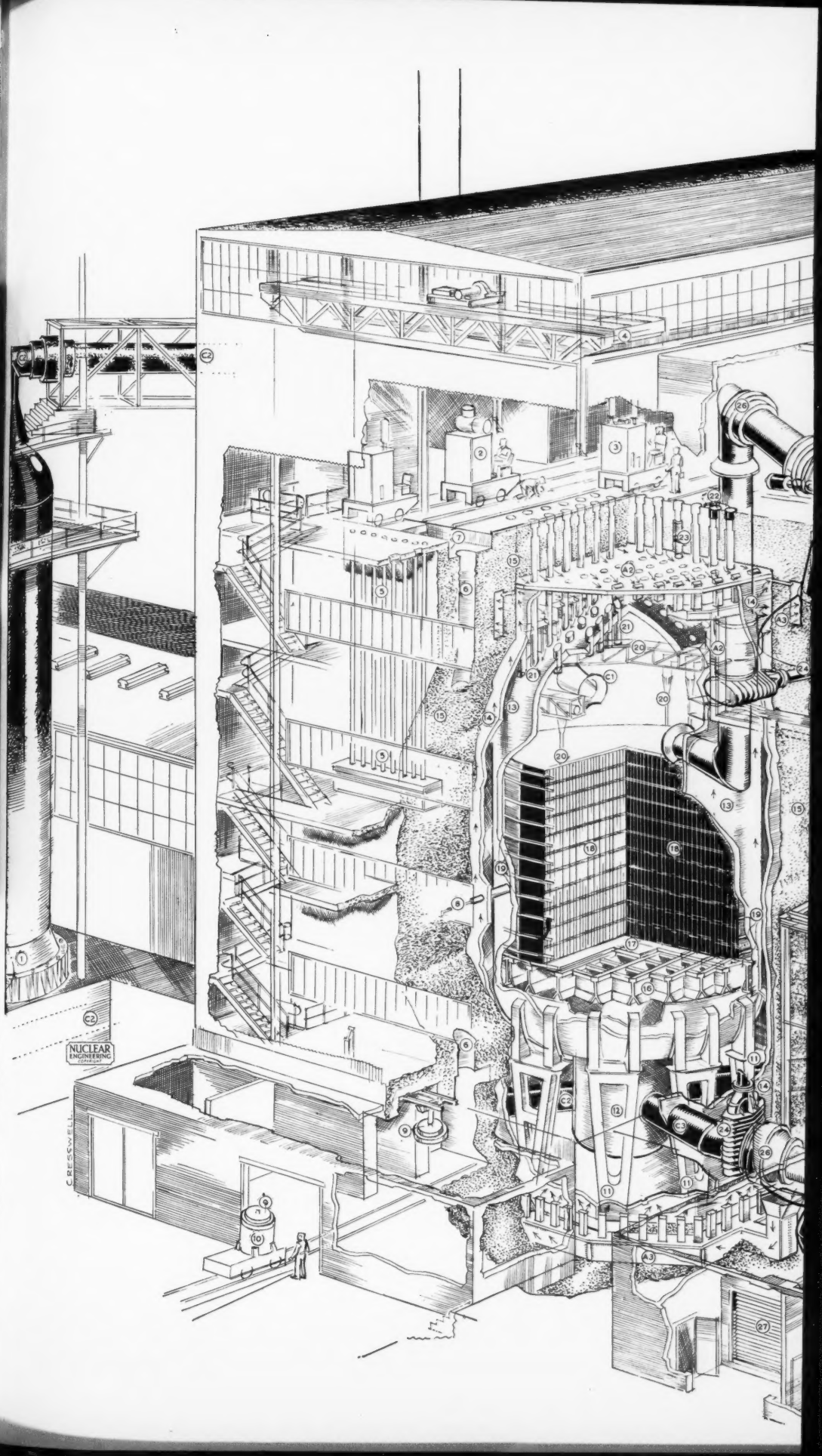
Stress-relieving and Testing

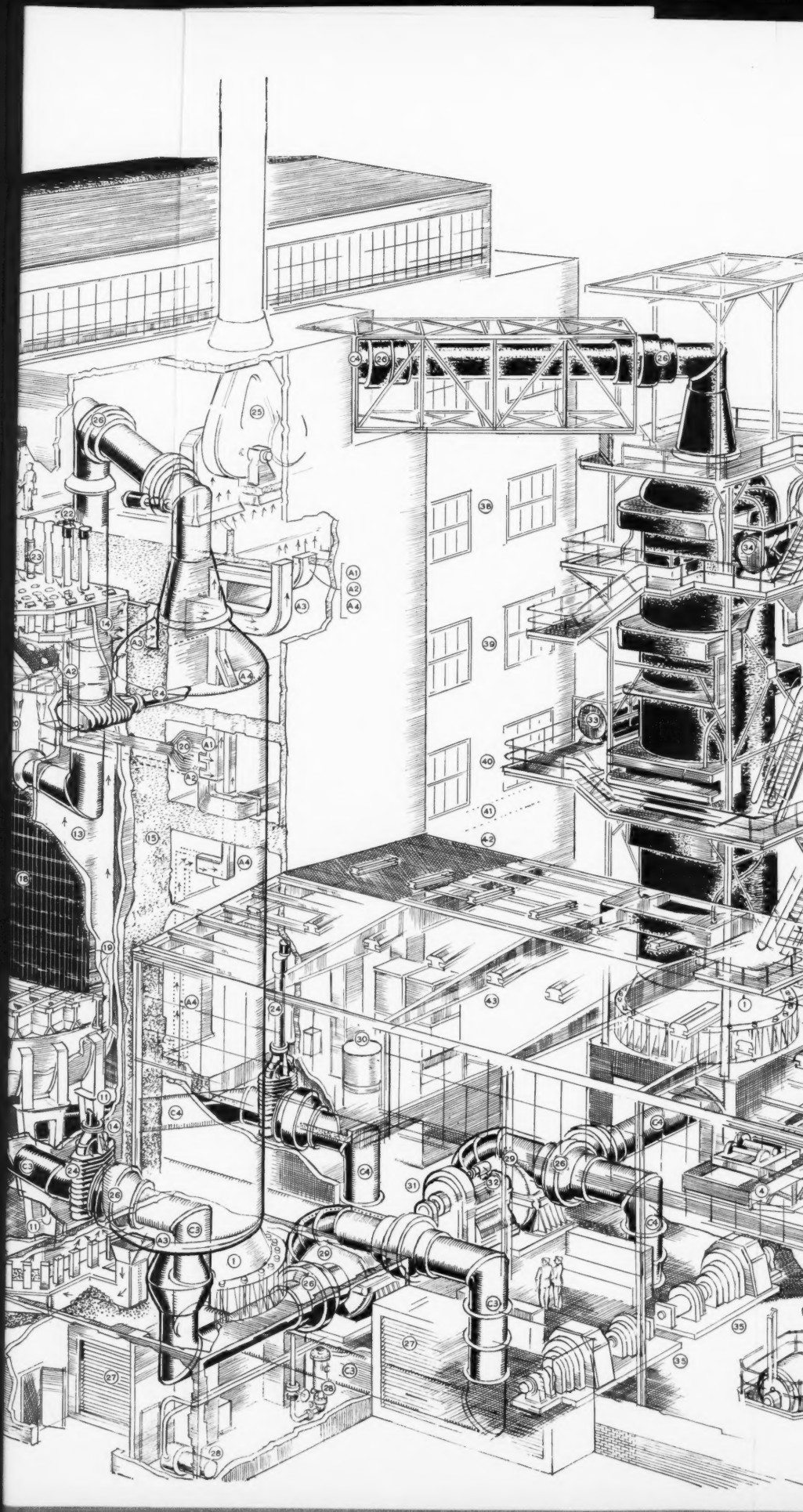
The stress-relieving of a vessel of this size presented considerable difficulty, but was finally done by lagging the vessel and installing a tubular framework to form a radiant heater inside the vessel. With a peak loading of 1½ MW, the vessel was raised to a top temperature of 1,110°F and a bottom temperature of 1,020°F over the course of some days and held there for eight hours before being allowed to cool.

Pressure testing by hydraulic means was impracticable owing to the weight of water involved, and pneumatic testing was employed, the behaviour of the vessel being examined by some 350 strain gauges to give the general stress level and to check the areas where locally high stresses might be expected. Brittle lacquer was used as a coarse check. After a preliminary run up to 50 p.s.i. and down again for the purpose of checking drift, the pressure was raised to 135 p.s.i. in stages. At each stage strain gauge readings were taken and any which showed that stresses were significant were checked more frequently. Brittle lacquer was examined at each stage after pressure had been dropped 10 p.s.i. from that at which strain gauge readings had been taken and stresses calculated; dimensional changes were recorded concurrently. This initial cold-air test was followed by a vacuum test; when the vessels were loaded with graphite the cold-air test was repeated to 115 p.s.i., this being followed by a hot test to the same pressure with air at a temperature of 284°F.

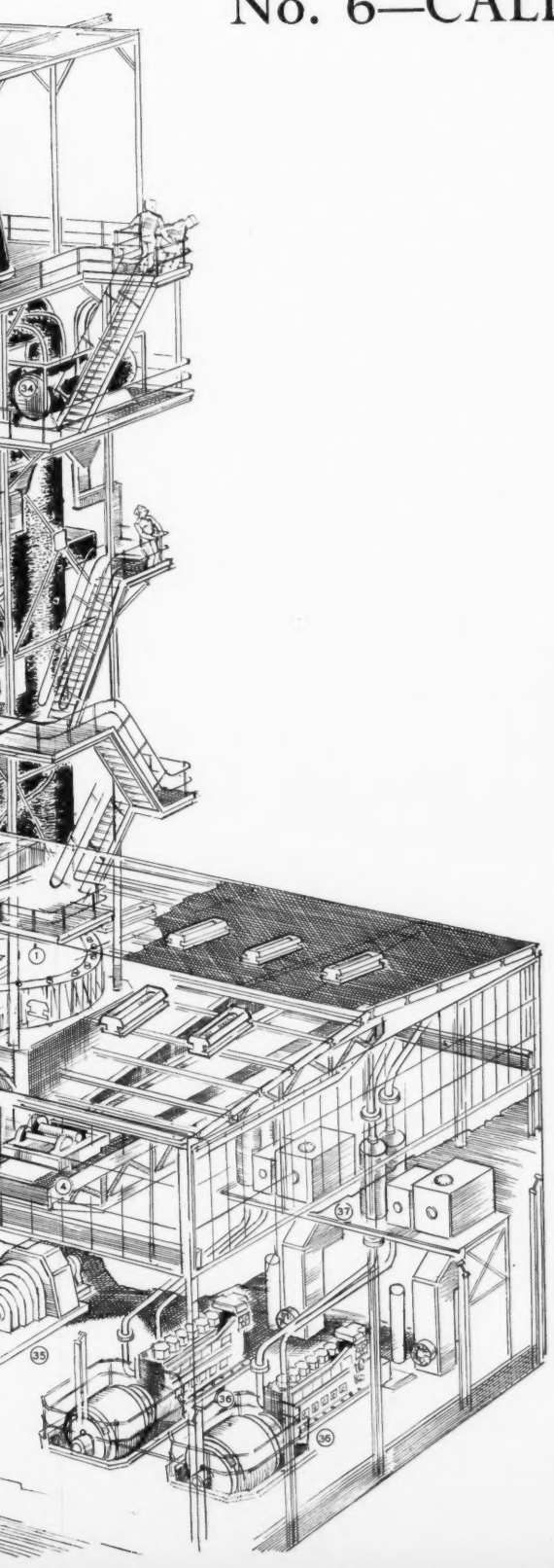
Inspection during construction was the responsibility of the Land Division of Lloyd's Register of Shipping. The strain gauge tests were carried out by their Research Department.

The final operation was the addition of thermal insulation. This was carried out by the Darlington Insulation Co. Ltd., using materials manufactured by the Chemical and Insulation Co. Ltd. The lagging was covered by aluminium plates.


NUCLEAR ENGINEERING
CRESSWELL



The World's Reactors
No. 6—CALDER HALL



KEY

A. Biological and thermal shield cooling circuits
C. Coolant circuits
1. Heat exchanger
2. Discharge machine
3. Charge machine
4. Travelling crane
5. Chute stowage tubes
6. Discharge well
7. Cross-traverse pit
8. Graphite probe
9. Flask lid
10. Transport flask
11. "A" frames
12. Inlet manifold
13. Pressure vessel
14. Thermal shield
15. Biological shield
16. Diagrid
17. Support plates
18. Graphite
19. Restraint rings
20. Burst-slug detection tubes
21. Charge tubes
22. Control actuating mechanisms
23. Shield plug
24. Motorized duct valves
25. Exhaust fans
26. Duct bellows
27. Cooling air filters
28. H.E. circulating pump
29. Main CO_2 blower
30. CO_2 purification plant
31. Blower motor
32. Pony motor
33. Low-pressure steam drum
34. High-pressure steam drum
35. Ward-Leonard set
36. Stand-by diesel generators
37. Diesel ancillaries
38. Fuel-preparation room
39. Burst-slug detection room
40. Control room
41. Cable gallery
42. Battery room
43. Switch room

The World's Reactors—No. 6

CALDER HALL: PIPPA—POWER AND PLUTONIUM PRODUCTION

INTERIM DATA

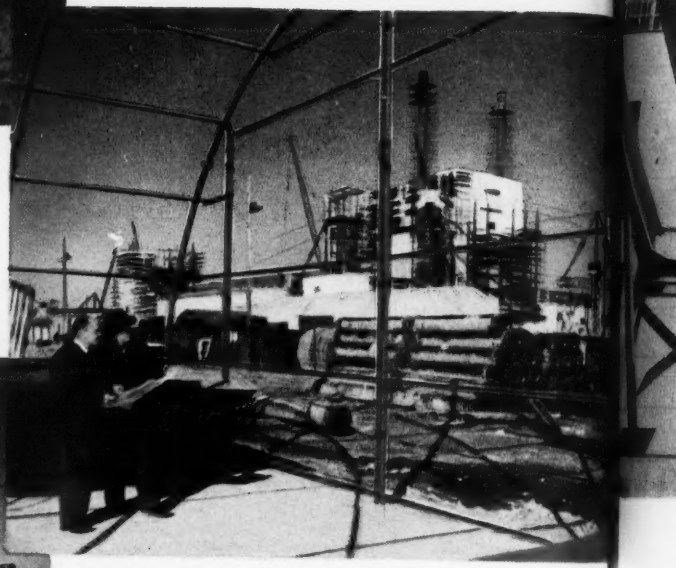
TYPE:	Thermal heterogeneous.
PURPOSE:	Plutonium production. Power production Prototype for central power stations.
LOCATION:	Sellafield, Cumberland, England.
CAPACITY:	42 MW from two turbines fed by four heat exchangers. Heat rating: 180 MW. Complete station includes four reactors. Maximum electrical output: 184 MW. Feed-back: 20%
OPERATION:	Diverged, May 1956. Opened by H.M. Queen Elizabeth, October 17, 1956.
FUEL:	Natural uranium. U as cast bars, 1.15-in. dia., 40 in. long. Elements in vertical channels, six per channel. Total number of channels: 1,696. Charge for criticality: over 20 tonnes. Total investment: 63 tonnes.
CANNING:	Magnesium alloy—Magnox. Wall thickness of core: 0.072 in. Extended surface: single-start helical fin, 0.125 in. pitch, 0.43 in. radial width, overall dia. 2.125 in. Manufacture: cans turned from solid, swaged on to U, He filled.
MODERATOR:	Graphite. Built up from 8 in. sq. interlocking blocks and tiles. Drilled 4-in. (av.) holes for fuel channels. Overall size, including reflector 36 ft. dia., 27 ft. high. Supported by ball bearings on 4-in. plates resting on diagrid. Total weight: 1,150 tons.
CORE:	Size: 31 ft. dia., 21 ft. high. Lattice: regular square, 8-in. pitch.
COOLANT:	Carbon dioxide at 100 p.s.i. circulated upwards through reactor. Flow: 7.1 million tons/hour. Ducting: 4 ft. 6 in. dia. Inlet temperature: 140°C. Outlet temperature: 336°C. Shielding cooling: blown air.
PUMPING:	Four centrifugal blowers, one in each heat exchanger circuit. Total power absorbed: 5.44 MW. Speed Control: Ward-Leonard type, range 10/1.
CONTROL:	Coarse: up to 60 rods ganged together. Fine: up to four manually operated. Normal operation: total of 40 rods. Rod construction: boron steel in stainless steel tubes. Suspension: stainless steel cable. Travel: 21 ft. Maximum rod speed for shut-off: 4 ft./sec. Minimum automatic rod speed: 0.5 in./min.
SHIELDING:	6-in. thick steel plates. Concrete, on sides: 7 ft., on top: 8 ft. Minimum density: 150 lb./ft.^{3}, mean: 160 lb./ft.^{3} Overall: octagon 60 ft. across flats, 90 ft. high. Total weight on foundations: 33,000 tons.

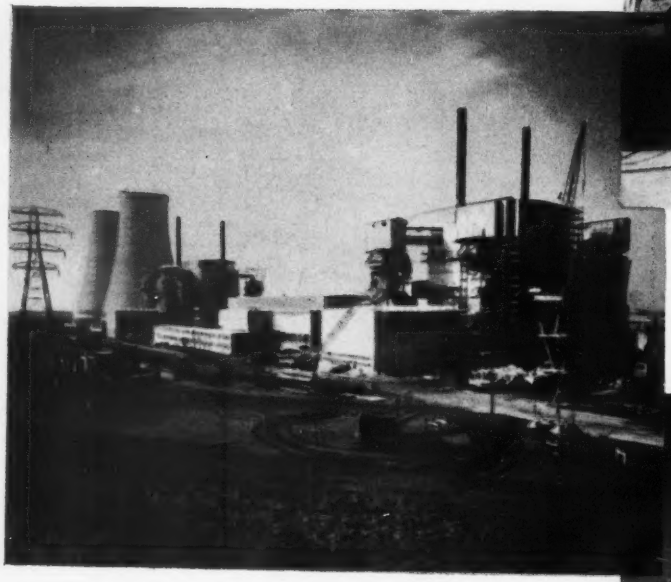
A limited supply of separate copies is available of this series of data sheets on various reactors built or projected throughout the world. Copies may be obtained from the publishers, Temple Press Limited, Bowling Green Lane, London, E.C.1, at the cost of packing and postage only (4d. *each*).

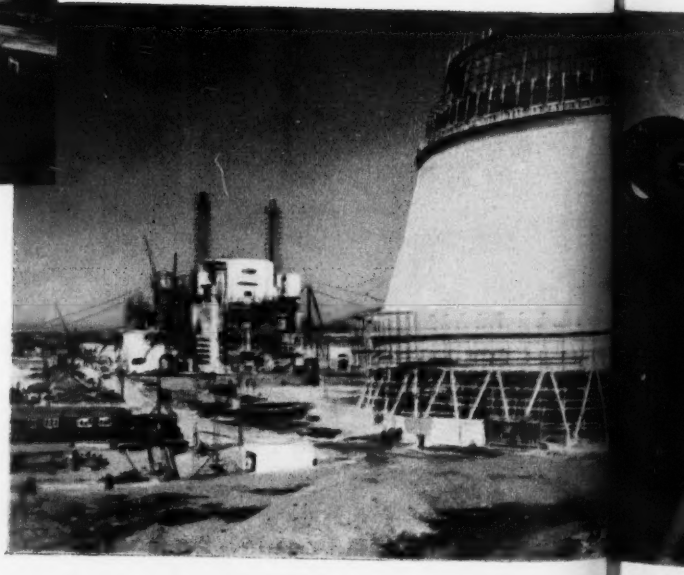
Data sheets in this series already published in "Nuclear Engineering" are:

No. 1. *BEPO* (*April*, 1956).
No. 2. *CP5* (*May*, 1956).
No. 3. *NRX* (*June*, 1956).
No. 4. *DIMPLE* (*August*, 1956).
No. 5. *ZEUS* (*September*, 1956).

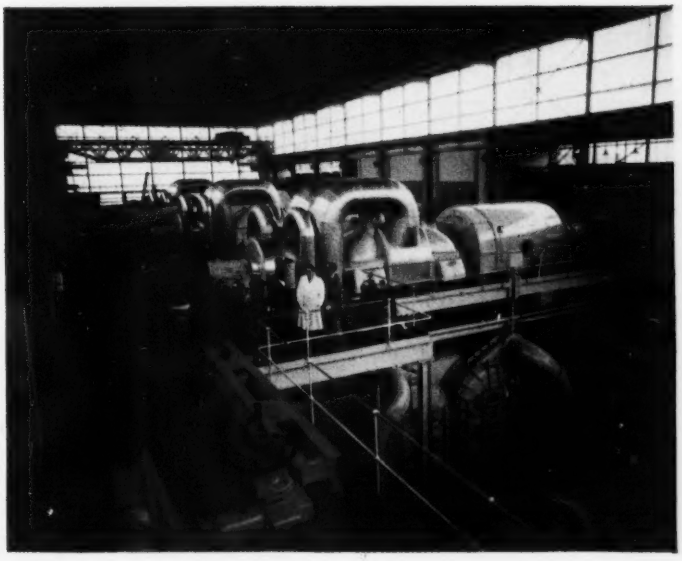
Ground was broken on July 22, 1953, and by the concerted efforts of the U.K.A.E.A. and the contracting companies commissioning trials were able to start in May, 1956.

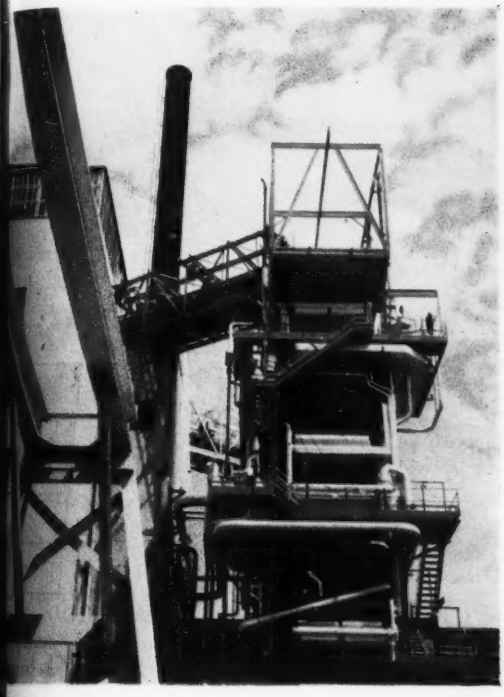


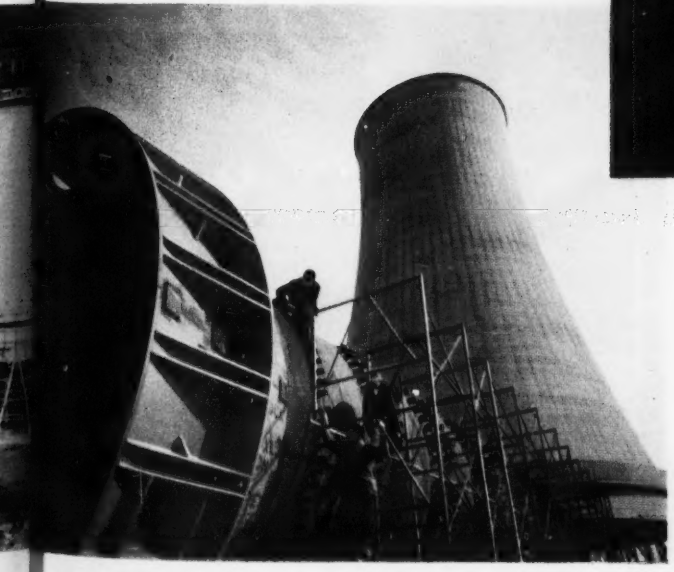




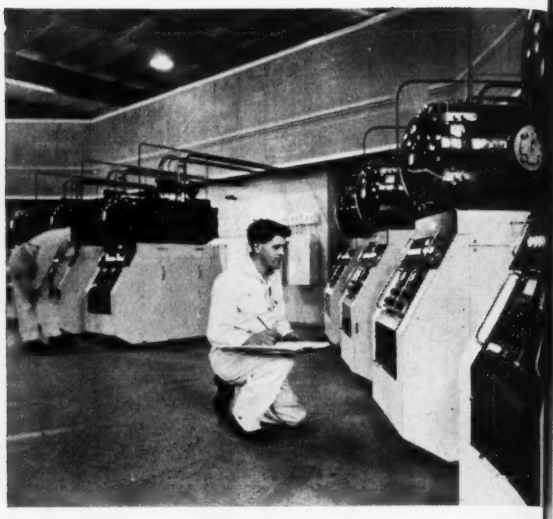
Stages in the construction of Calder Hall.



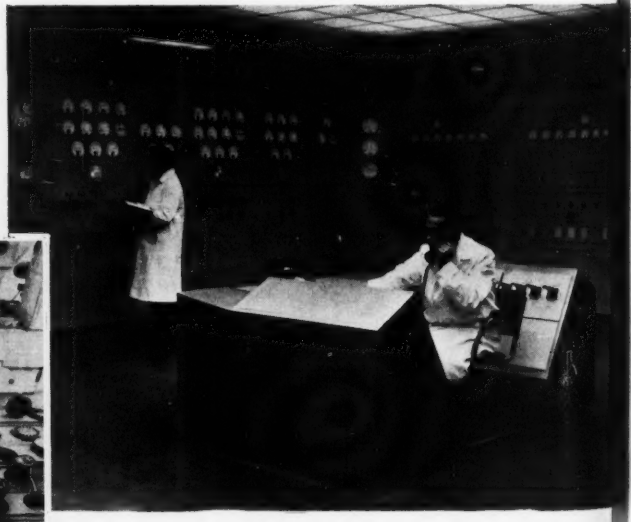




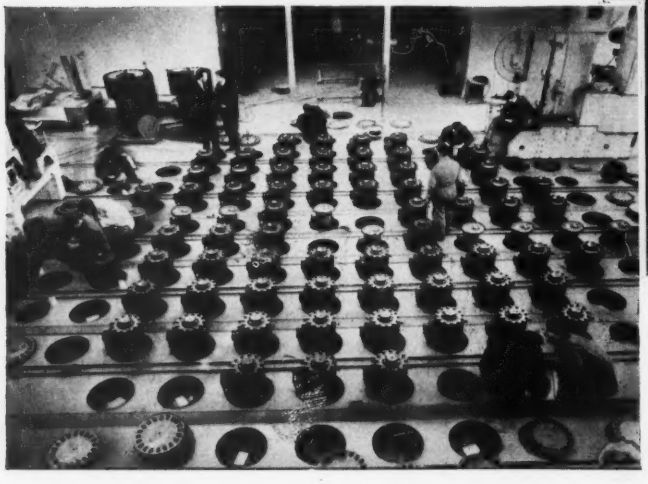
Details of the turbine house, heat exchangers, and reactor control room.

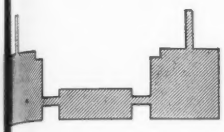


(Above) The burst-slug-detection gear.
(Left) The lower dome of the pressure vessel is lowered into the concrete shield.



(Right) The completed electrical control room.
(Below) General view of the charge floor during the commissioning trials.





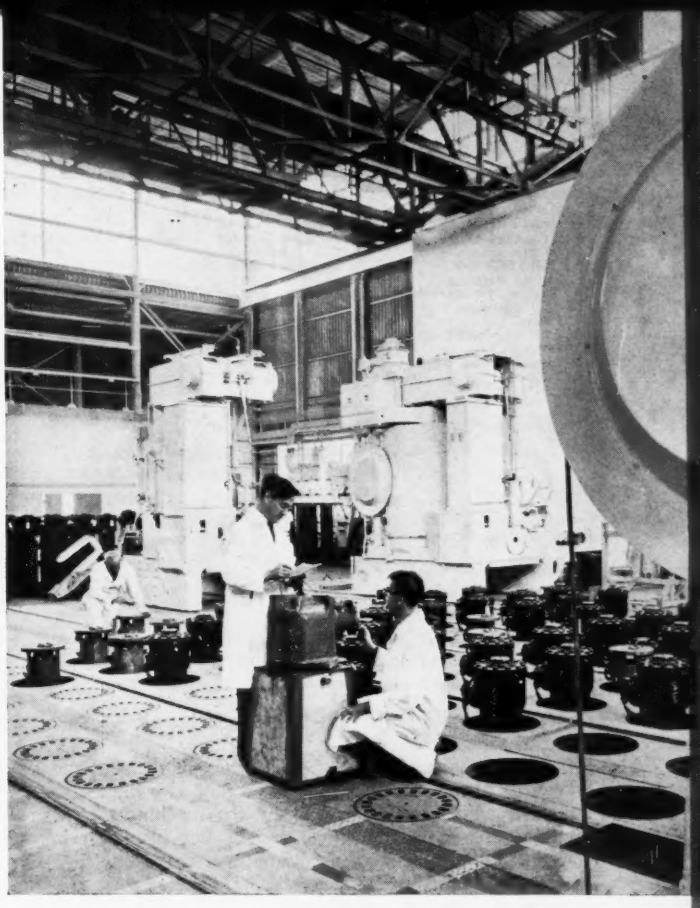
Charge and Discharge Gear

REGULAR replacement of burnt-up or damaged fuel elements is an essential part of reactor design. Previous experience in the United Kingdom on large graphite-moderated reactors has been limited to reactors built with horizontal fuel channels and without a heavy pressure shell. Structural and load considerations ruled out the horizontal system at Calder Hall and new equipment had to be constructed for charge and discharge. This work was undertaken by Strachan and Henshaw, Ltd., Bristol. Whereas with BEPO and the Windscale reactors loading and unloading could be performed directly in line with the fuel channels and each element could be used to push the next element farther into the channel or out into the discharge coffin, the Calder reactors demanded that access should be available from one face only and the strength of the ellipsoidal ends decreed that one entry hole should serve a number of fuel channels. From the top face of the pile to the top of the dome is a distance of 19 ft. and from the top of the dome to the underside of the top thermal shield a further 3 ft. The 6-in. thermal shield is separated from the biological shield by a 6-in. air gap and the concrete above this is 8 ft. thick. All in all, from the charge face to the bottom of the fuel channels there is a vertical drop of 57 ft.

The individual fuel elements have an active length of 40 in. and are constructed of magnesium alloy. Each is provided with a single start helical fin of narrow section and a radial width of 0.41 in.; total weight per element exceeds 28 lb. It is important for good heat-transfer characteristics that this finning is undamaged. Apart from decreasing efficiency of the reactor as a whole, distortion of these fins is liable to cause local overheating, excessive distortion of the uranium rod and early failure of the can, and the elements should, therefore, be treated with great care and excessive sideways pressure avoided. The system of handling adopted only partially fulfils this function and some slight local bending of the fins can occur during charging operations. Damage (except gross damage) during discharge is of no importance, although it is equally important that the graphite channels should not undergo undue wear. The elements sit vertically over one another in the channels, each element being located by a male cone fitting into a female cone in the top of the element below. At the ends of the elements spiders are screwed on which serve the dual purpose of locating the elements centrally in the channel and providing three radial supports for the lifting grab to catch.

It is essential that this grab should firmly pick up the elements and lock into place, as a disconnection towards the top of the reactor which allowed an element to plunge vertically, say 50 ft., could cause considerable damage to itself and other elements in spite of cushioning provided at the bottom of the channels.

Ideally, charge and discharge should be possible with the reactor running at full power. Again ideally, it should be possible to move the elements during their life quasi- continuously from parts of the reactor of low reactivity towards the centre where reactivity is greatest; also, for maximum efficiency, individual damaged elements could be detected and removed without the necessity for discharging a complete channel.



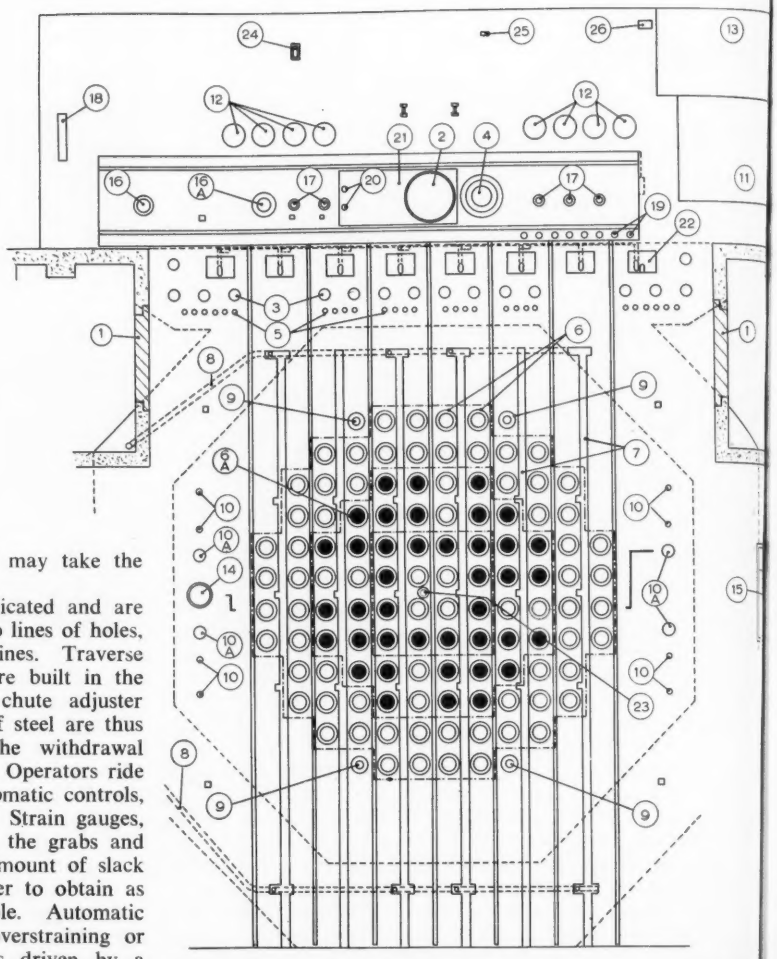
The charge floor seen from the discharge-well side. The control-rod actuating mechanisms are proud of the floor.

At an early stage in the project it was decided that time did not permit the development of a system that would fulfil this specification. The charge and discharge gear, as a result, has been designed for operation only on shut-down with the reactor depressurized and provision has been made for the handling of elements by channels only, discharge always being to the magazine for transfer to the Windscale processing plants. Complications are introduced by the 40 control rods and operating mechanisms and ion-chamber probe connections, which are also located on the charge floor and use the same openings through the biological shield and pressure shell as the charge and discharge gear.

The upper face of the graphite pile is covered with a series of heavy cast-iron plates, one plate for 16 fuel channels with a central hole to take control rods, ion-chamber probes or the chute locating spigot. The plates are provided with chamfered entry holes vertically over the fuel channels. Centrally located over the centre of each 16 are the stub tubes through the pressure vessel dome. These were welded into the dome before the pressure vessel was built up and extension tubes were then welded into position with the pressure vessel *in situ*. To avoid radiation leakage, the tubes are stepped corresponding to the stepped liner in the biological shield. To cater for differential expansions the tubes are otherwise a loose fit in the liners and cooling air is circulated through the annular gap by the thermal shield fans at an equivalent rate of 10,000 c.f.m.

Normally, these tubes are blanked off with stepped, concrete-filled steel plugs, the step located half-way down the length forming a nearly gas-tight metal-to-metal cone seal which still allows some relative movement to cater for thermal differences; a final pressure seal is made with a flange joint at the top. The control-rod drives pass through the centre of the plugs and the top seal is then made by the control-rod

1. Removable panel
2. Discharge well
3. Mortuary holes
4. Hydraulic cylinder
5. C.R. mortuary
6. Charge tubes
6a. C.R. positions
7. Service trenches
8. Machine purge system
9. Contamination test holes
10. Remote viewing holes
11. Hoist well
12. Charge chute stowage
13. Stairway
14. Access hole
15. Removable panel
16. C.R. test hole
17. Grab access holes
18. Ancillary CO_2 feed
19. C.R. stowage
20. Door hydraulics
21. Cross traverse
22. Charge machine contacts
23. P.V. probe
24. Oil pipes
25. Hoist footing
26. Cable slots



Plan of the charge floor. Charge tubes on a 2 ft. 8 in. pitch serve 16 channels. Control-rod heads, shown shaded, comprise 40 in all.

drive heads. Similarly, ion-chamber probes may take the place of the control rods.

The two machines (see opposite) are duplicated and are arranged to run on railway lines spanning two lines of holes, either of which can be served by the machines. Traverse facilities are provided at one end. They are built in the form of a carriage to accommodate the chute adjuster between the parallel supports. Some 6 in. of steel are thus interposed between any element during the withdrawal process and personnel working on the floor. Operators ride on the machines and, by means of semi-automatic controls, operate the grab mechanism and magazines. Strain gauges, torque indicators, etc., show the position of the grabs and magazines, the position of the grab claws, amount of slack cable and tension on the cable, etc., in order to obtain as rapid and efficient a performance as possible. Automatic interlocks on the pick-up motors prevent overstraining or undue slack on the cables. The winch is driven by a reversible motor with a wide range of controlled speed; maximum rate of travel of the grab is 175 ft./min. The charge and discharge magazines are basically similar in design —24 sockets arranged to carry elements in a vertical position in an annular ring about 3 ft. in diameter. General appearance is not unlike a revolver magazine, but the discharge unit requires heavy shielding to protect operators against fission product radiation. This takes the form of a heavy casting weighing approximately 30 tons surrounding the basket, which can be lowered down the discharge well to a bogie on the ground floor for transport to Windscale. The magazine itself is cooled by CO_2 circulated through air-blown radiators mounted on the discharge machine.

The special grabs have been designed to engage automatically the spider carried on the top of the fuel elements and similarly to disengage when the load is removed. The claws are operated by a 45-V D.C. motor with angular movement limited to 17° located immediately over the grab. Suspending cable has been specially constructed to withstand the high temperatures and radiation levels by British Insulated Callender's Cables Ltd., with a 110-ton stainless-steel core wound with six 19/0.0076 nickel-plated copper P.T.F.E. insulated wires. This in turn is covered with a silicone-rubber sheath and braided with Terylene. It has been recognized that no system is accident-proof and that grabs and cans may fail. A range of hooks and tongs has therefore been devised which can engage disconnected grabs or, through suitably articulated linkages, elements can be picked up direct. These instruments can be operated by a small hand-wound winch, or directly from the charge face. Overload meters on the machines, however, give early indication of difficulties and no serious problems are expected to arise. An experimental grab with electro-pneumatic control has also been built. This is suspended by a cable with an additional flexible stainless-steel tube.

The chute is constructed of two tubular sections, one of which is pivoted about a rod fixed to the rigid tube approximately 12 ft. from the lower end. The rigid tube, or tube section, is provided with a central spigot at the bottom which locates in the hole provided in the centre of each graphite cover plate. Rotation of this section and suitable adjustment of the relative angle made with it by the second tube allows any one of the 16 channels to be selected. Control is exercised through a system of shafts and gears which are connected to manual drive wheels in the locater unit by universal joints. The elements pass through the centre of the pivoted tube into (or out of) the cover-plate extension tubes. Indication of the position of the chute is given on large clock dials on the locater unit. This system of channel selection means that elements slide down the chute, resting at the bends on the finning, and some slight local distortion can result. The angle of the chute at its extreme position has, however, been kept to a minimum to reduce this effect.

Used magazines arriving from Windscale are loaded into a dryer made by Royce Electric Furnaces Ltd., to minimize the chance of contaminating the reactor. Spent fuel elements in their magazines are transferred across the charge floor still in the discharge machine over a well normally closed by a heavy sliding door. This door is opened and the basket is lowered down the well to a waiting bogie on the ground floor. The bogie carries a 20-ton flask filled with water, the lid of which is remotely lifted by a ram and replaced on receipt of

the magazine, the water acting as both additional shield and coolant. The bogie is moved under a scaffold, the flask lifted off and reloaded on to a special lorry for transport to the Windscale storage ponds.

Handling of the shield plug, control-rod drives, etc., is by a travelling crane spanning the charge floor 64 ft. across provided with a grab with twin hoisting motions of 7.5- and 1-ton capacities. The crane is required to have a more sensitive movement of lift than normal and Ward Leonard control has been installed to give a smoothly variable motion from full speed down to creep speeds.

A change of fuel discharge is accomplished in the following way.

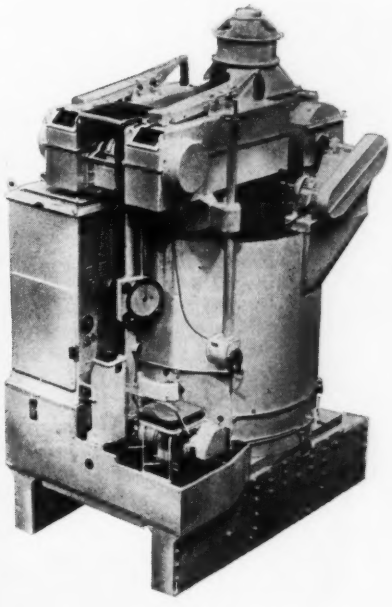
The reactor is shut-down and the steam is diverted to the dump condenser. When the drop in heat output has levelled off, the CO_2 pressurizing is discharged to atmosphere, the reactor being maintained at a pressure slightly in excess of ambient. The 12 securing nuts are then removed from the sealing gland and the (say) control-rod drive removed by the crane. Leakage of CO_2 at this stage is prevented by the metal-to-metal joint. A temporary gland and gate valve is fitted over the flange and CO_2 is supplied to the top end of the charge tube at a pressure of 2 in. w.g. External leakage is dissipated by local blowers. The shield plug can then be withdrawn. The locater unit is positioned over the hole and the charge chute lowered into position; the universal joints connected and the pivoted tube adjusted over the appropriate fuel channel.

The discharge machine can now be driven up and positioned over the chute. The appropriate winch is brought into operation and the grab lowered for the first fuel element. This is lifted out and placed into the magazine and the process repeated. The magazine is successively rotated by the operator to bring the empty container tubes into position in order. When the channel is empty the locater controls are adjusted to serve another channel. When discharge is complete or the magazine full, the machine moves to the traverser and then over the well, down which the magazine is lowered to the waiting bogie. In the meantime a charge machine is brought up and the reverse procedure adopted.

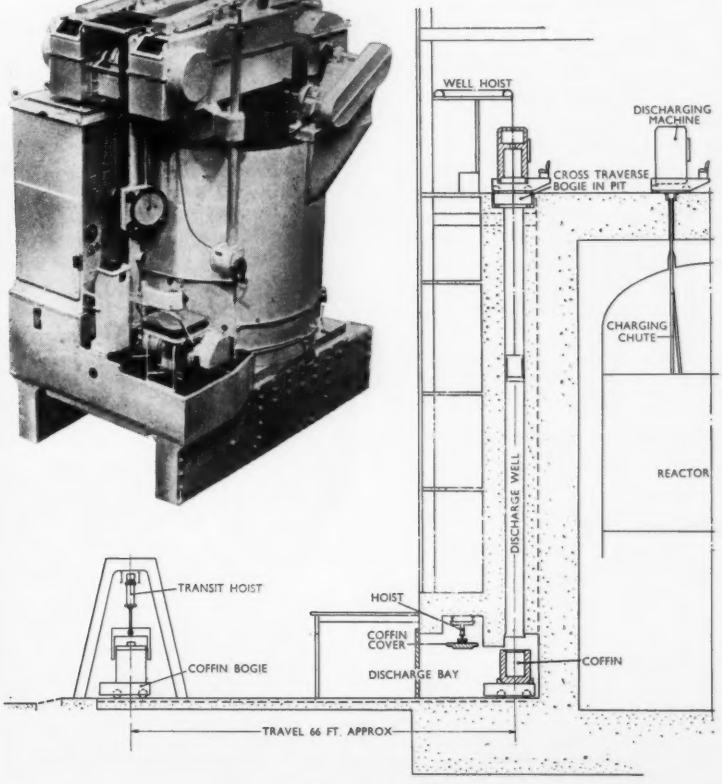
The time required for the charge and discharge of one group of four channels amounts to about 1¼ hours and it is imperative that replacement of fuel elements is necessary at only infrequent intervals. The time involved is not made smaller by the number of different pieces of equipment necessary nor the number of operation. A single machine which could handle a complete change on its own would allow the process to be speeded up considerably, but the greatest delay would still occur during shut-down and start-up periods, i.e., for an element fault. Bulk fuel changes even on a commercial power reactor could be timed for off-load periods. Having taken the decision not to charge and discharge under load, the additional time and effort required to produce a more highly developed system would not have been justified. The process, if laborious, is nevertheless certain and this is the more important feature.

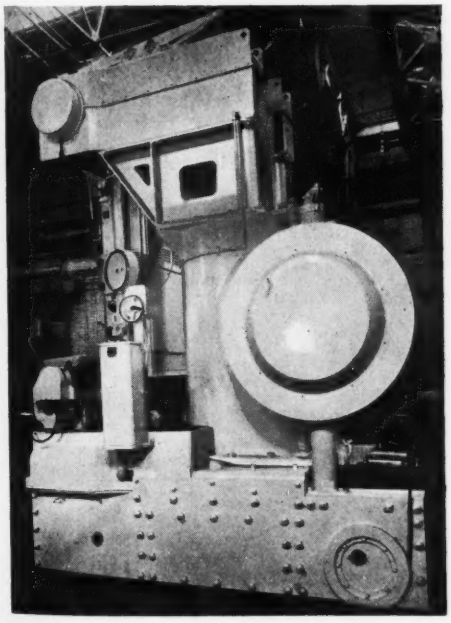
Probably the most fundamental step in moving from a plutonium-producing reactor, such as Calder Hall, to an economic power reactor concerns the design of the charge and discharge equipment, and we must expect that tenders to the C.E.A. have included considerable advances on the system discussed here.

(Right) Discharge machine of basically similar construction to the discharge, but provided with a heavily screened, CO_2-cooled demountable magazine, making total weight 60 tons.

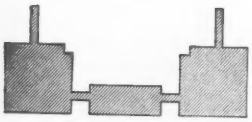


(Below) General arrangement of discharge facilities. Full magazine is lowered into water-cooled coffin for transfer to the Windscale ponds.





(Above) Charge machine weighing 12 tons, controlled by operator riding on seat on the left. Magazine holds 24 elements.



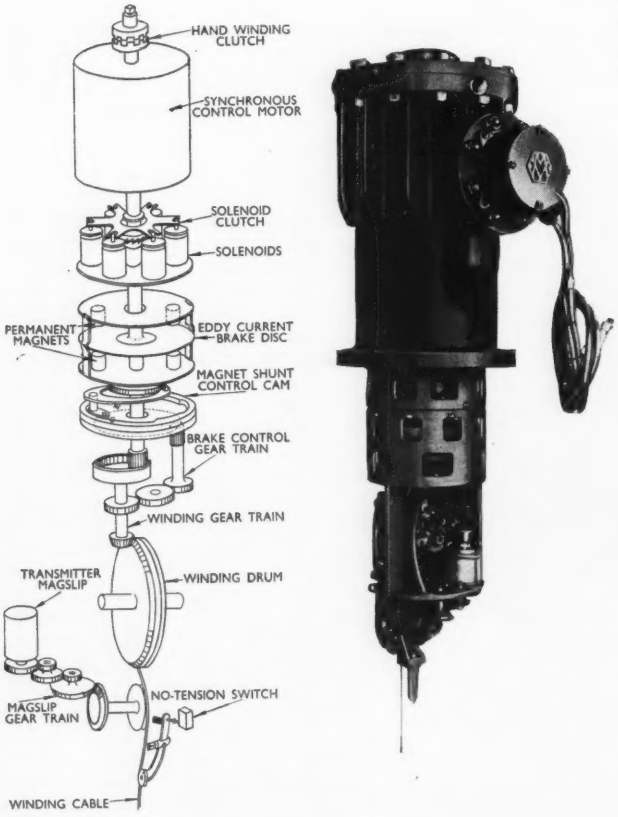
Reactor Control Rods

THE control rods in the Calder Hall reactor move vertically parallel to the fuel-element channels and provision is made for the operation of one rod in the centre of each 16 fuel channels. Not all these will be used during normal operation, and the pattern of 40 at present adopted can be seen in the drawing accompanying the discussion on the charge and discharge gear. The rods are made of stainless steel lined with a boron steel gauze and weigh approximately 130 lb. They are required to travel over the full depth of the reactor core—21 ft.—and are suspended from the head units mounted on the ends of the charge tubes at the control face by a stainless steel cable. The rods are required to operate in two groups, a coarse and fine, which can include up to 60 and four actuating mechanisms respectively. No additional provision is made for shut-off rods. The coarse rods are provided with three operational speeds, 50 in. per minute, 5 in. per minute and 0.5 in. per minute, and with all the rods moving out together the change in δk is limited to 2×10^{-6}/sec. The fine control is normally manually operated—maximum speed 50 in. per minute—but, during commissioning, fast speeds, both in and out, were made available.

For shut-off, the rods are required to accelerate rapidly to their maximum speed to pass through the core at approximately constant speed and then slow down before meeting the cushioning at the bottom of the holes. Initial acceleration is not less than 2 ft./sec.^{2}, whereas a maximum speed is 4 ft./sec. and touch-down not greater than 6 in./sec. The minimum design time of travel through the 18½-ft. centre of the core is 5 seconds. The stored energy of the control rods is absorbed by forcing a broach into a stainless iron sleeve at the bottom of the reactor.

The actuating mechanism shown below (left) comprises the synchronous driving motor of variable reluctance type with a three-phase wound stator class H insulated and unwound rotor, driving through a solenoid clutch and an eddy current brake, a gear train which in turn controls the cable wound in a single coil between the side cheeks of a drum.

Variable braking is achieved by a cam-operated magnetic shunt driven from the gear train. Position of the control rod is transmitted by a magslip driven through a gear train by a pulley running on the suspension cable. Loss of tension on the cable is indicated by the movement of the switch operated by a follow wheel also directly on the cable. For



Above: The actuating mechanism with a simplified drawing of the gear trains, eddy current brake and cable position and strain detectors. The lower flange bolts on to the top of the charge tube, the junction box remaining proud of the charge floor.

Below: Main sine-potentiometer cubicle. Two potentiometers, each providing a three-phase signal of frequency determined by the speed of rotation of the hand-wheels, provide fine control on a maximum of four rods.

emergency winding a manual-operated dog can be engaged on to the motor shaft. Step-down from the motor to the drum gives a 20:1 reduction ratio. The cable is attached to the control rod by a special stainless steel coupling which drops over the head of the rod. A remotely-operated bolt locks it in position.

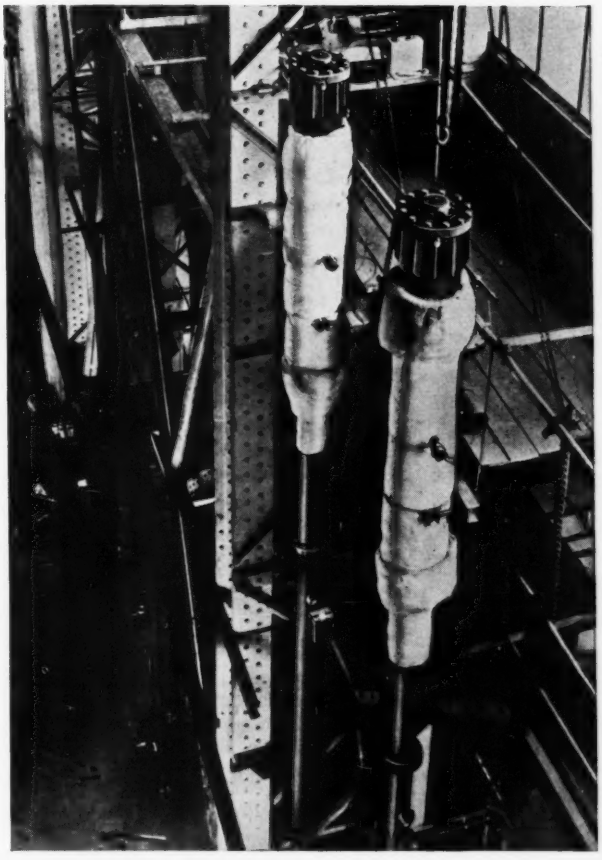
For operation in the oxygen and water-free atmosphere and to avoid contamination of the CO_2, molybdenum disulphide has been used as lubricant. The mechanism has, of course, been designed to operate in a pressure of 100 p.s.i., but also at a temperature of 100°C.

Extensive life tests were carried out not only on individual components but on two actuating mechanisms which were run in an atmosphere of pure, dry CO_2 at a pressure of 100 p.s.i. Mechanisms were lagged and heating was incorporated to simulate operational conditions. Successive tests were run at the highest rod speed with automatic reversal at the top and bottom of the travel. The control system is based on variations in frequency and phase sequence of a three-phase supply to the driving motors, with a range of 0 to 1.3 c/s at 40 V r.m.s. Zero frequency with D.C. supplies to the driving motors provide a locked hold position and range speeds can be selected from the distribution cubicles.

Supply to the coarse control is generated by a frequency converter set, the second being available as a stand-by. With the control rods ganged, position is indicated via a magslip transmitting from the frequency converter set. Fine control supplies come from two sine potentiometers comprising a resistor chain fed by D.C. and tapped to give a sinusoidal distribution of potential. Tapping points are taken up to studs on the face plate, from which brushes pick off a three-phase supply at a frequency equal to the rate of rotation.

The frequency converter consists of a 37.5-h.p. inductive driving motor, a 22-kVA salient pole, an A.C. generator, a differential gearbox, and a 19.4-kVA frequency converter mounted in line on a common bed plate. The generator is excited from the 50-volt station battery. The frequency converter has no stator winding and is rotor fed through six slip rings from the A.C. generator. The three-phase output is taken from brushes arranged around the commutator. Drive power is supplied by the inductive motor through the differential gearbox. The value of current from the output brushes is a function of the positional relationship of the rotors of the two machines. If a decrement of speed is fed into the differential gearbox, the frequency converter runs sub-synchronously and the three-phase supply is drawn from the commutator, the frequency corresponding to the difference in rotational speeds of the two machines. The system is designed to move the rods "in" when the frequency converter is run sub-synchronously to provide a fail safe condition.

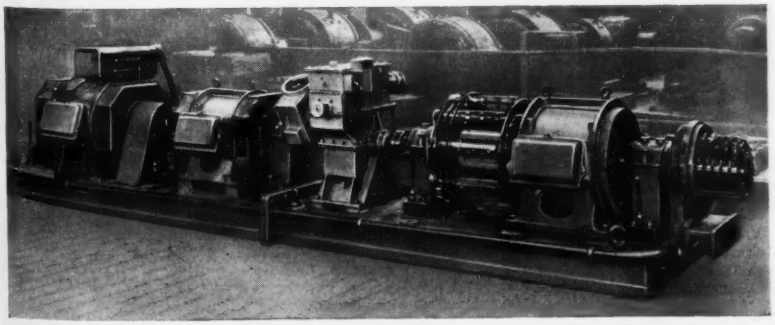
Emergency shut-down for the reactor is initiated from the emergency push button on the reactor control desk or from one of the shut-down circuits which will operate on a number of fault conditions, such as coolant flow and pressure, neutron flux, reactor temperature, etc. All line contactors and circuit breakers are opened, removing control supplies from the main busbars and de-energizing the actuating mechanism so that the rods fall, braked only by the eddy current brake. In the event of the solenoid clutch failing to disengage, the motor will backrun. At the same time the sine-potentiometer supply is tripped and the fine rods also give a shut-off action. The main turbines and A.C. generators are tripped from relays operating on under-voltage at the main busbars, so preventing the turbines being motored.



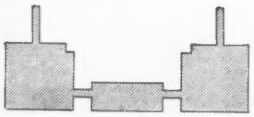
Two control-rod systems under test. Heating elements and insulation simulate operating conditions. Exhaustive experiments were carried out on the efficiency of solid lubricants.

For fuel changing the operating mechanism is raised by the crane, the cable being paid out at the same time with the control rod resting on top of the core. The cable is then released from the winding head and, following removal of the shield plug, the rod can be withdrawn and transferred to the storage holes.

The complete control rod equipment was manufactured and installed by Metropolitan-Vickers Electrical Company Limited, Trafford Park, Manchester.



The frequency converter set on test. The drive motor, generator, differential gearbox and frequency converter are mounted in line on a common bed plate. A second set is installed as a stand-by.



Burst-Slug Detection Gear

ONE of the hazards that must be guarded against in the operation of a heterogeneous reactor is the possibility of fuel-element failure resulting in the release of large quantities of fission products into the coolant system and creating radiation hazards in sections of the plant normally occupied by operating personnel. A single accident of this type would probably not raise the background radiation to a dangerous figure, but it would certainly cause considerable trouble and considerable complications in the maintenance of machinery and plant in the coolant circuit. A series of accidents of this type, however, could easily put the plant out of commission.

Quite apart, therefore, from the comfort of operation, a long reactor life demands that early indication should be given of any fuel-element failure so that steps can be taken before any gross fracture in an element is possible.

Fortunately, even before the fracture is discernible the thin wall or pin-hole allows gaseous fission products to pass through and these mix with the gas stream and can be detected externally to the reactor core by continuously monitoring a bleed from the coolant. Detection depends upon the formation of solid daughter products from the gaseous fission products which can be precipitated by semi-conventional dust precipitation techniques and counted by conventional detecting equipment.

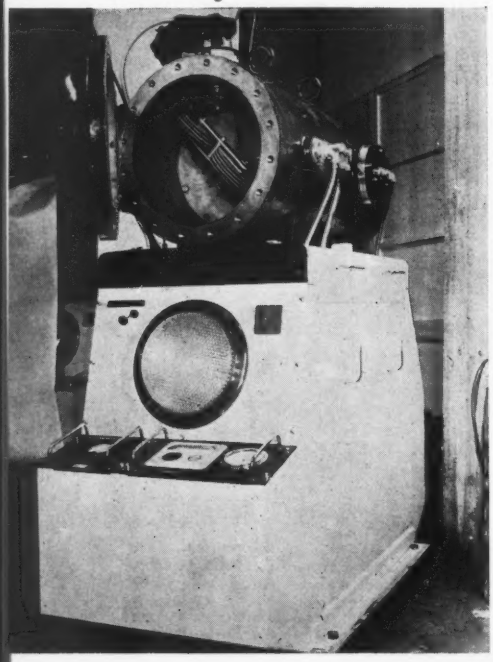
Design of the equipment was undertaken by Plessey Nucleonics Ltd. in co-operation with the U.K.A.E.A.

Each of the 1,696 fuel channels is provided with a stainless steel tube at the upper end which bleeds off a small fraction of the gas passing through the channel. The tubes are led out of the reactor in eight groups of 212 through a stainless steel plug welded to the stub tubes in the pressure vessel and through the biological shield, again in eight groups of 212, passing through mild steel plugs. Groups of four tubes from adjacent channels are then fed through valves into header units and the outlets from these units, comprising 424 in all, are fed to eight rotary valves of one pole 54-way each. The outlets from these valves are fed through filters and coolers to eight chambers, in each of which is housed the precipitation unit and radiation detection gear. For ease of manufacture valves have been constructed with the inlet ports in two banks, and one way has been blanked off, leaving a total of 53 effective ways per valve unit. The gas is cooled before entry into the chamber to simplify construction from the point of view of bearings, insulators, etc. On emerging from the chamber, the gas returns to the inlet side of the main blowers.

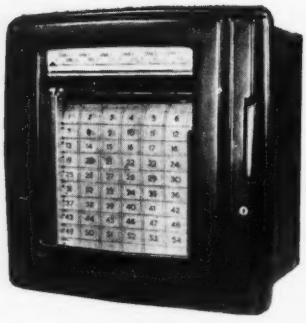
Very considerable lengths of pipe are involved in the overall construction, there being approximately 120 ft. of ½-in. stainless steel tubing per channel, giving a total length of approximately 40 miles. Numerous joints were therefore required and Delapena induction-heating equipment was employed to braze the butt ends of the connecting tubes into a stainless steel ferrule. The heating equipment, which was designed so that it could be placed inside the reactor, has a power rating of 20 kW and operates at a frequency of 500 kc/s. Installation of the gas circuits was carried out by Matthew Hall and Co. Ltd.

The heat exchangers were constructed by Marston Excelsior Ltd. of stainless steel and great care was taken to ensure that no contamination of the CO_2 was possible by fluxes introduced during the course of manufacture. Each heat exchanger is built up of two identical matrices to allow the gas to make two passes through the cooling air. The matrices are built up of flat plates bearing cold-pressed ribs and these plates, when welded together in pairs, form a series of narrow channels through which the CO_2 passes. Individual pairs of plates are separated by a stainless steel corrugation through which the cooling air passes. A complete matrix was assembled with brazing foil separating plates and corrugations and the whole assembly soaked at a temperature of over 1,000°C. After brazing, the pack was thoroughly cleaned and all seams argon arc welded.

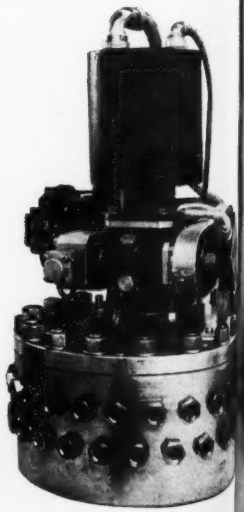
A complex system of interlocks ensures that the group of four channels under examination is correctly indicated. The



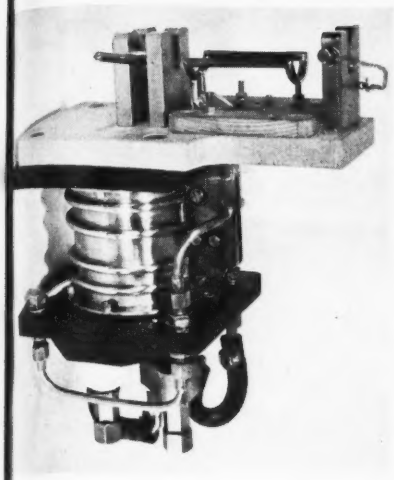
(Left.) One of the precipitation chambers with pressure door open. Two of the Tufnol pulleys carrying the wire maintained at a potential of 4 kV can be seen. Drive for these is obtained from an externally mounted motor.



(Left.) The Elliott 54-channel recorder is provided with nine pens and six zero-set positions. Fed by the scintillation counter ratemeter, a record is shown of the fission product activity in the bleeds from 212 channels grouped into fours.

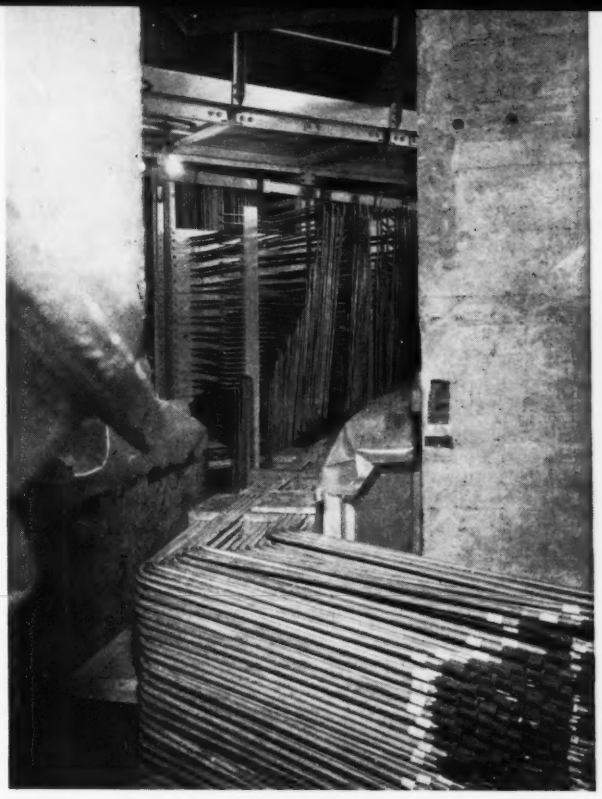


(Right.) The 53/54-way, 100 p.s.i. pressurized rotary valve, which allows each group of channels to be monitored in turn. The magslip mounted on the top indicates in the control room the group under test.



(Left.) Portable work coil unit for the Delapena induction-heating equipment used for brazing together lengths of stainless steel piping of the burst-slug detection gear. Details of the output transformer are visible.

(Above, left.) 212 ½-in. stainless steel tubes forming one of eight groups monitoring the 1,696 fuel channels. Provision is also made for monitoring the outlet gas ducts.



(Above.) General view of the complete array of sampling tubing leading from the biological shield to the individual valves and 424 headers.

count rates associated with the 53 ways are progressively shown on an Elliott 54-way recorder provided with a chart divided into 54 sections in six columns and nine rows.

Basically, this instrument is an Elliott self-balancing potentiometer recorder with the following modifications—additional gearing has been provided to enable chart speeds of 1 in. in 24 hours to be achieved; the normal chart paper has been replaced by Teledeltos electro-sensitive paper; and instead of a single pen on a moving carriage this has been equipped with pen bars carrying nine tungsten pens equally spaced vertically down the chart. The appropriate channel of the recorder is selected by means of two cam switches fitted to the 54-way valve. These of six-way and nine-way individually select columns and rows. To make certain that the gas duct under test is correctly positioned on the chart, the recorder channel selector also feeds a signal to a dial mounted in the control room. This dial has 54 neon lights arranged round the circumference with a centrally mounted pointer driven directly from the magslip mounted on the valve. With correct operation, the pointer indicates the lit neon.

The count is made by a conventional scintillation counter using a plastic phosphor manufactured by Nash and Thompson Ltd. as detector. Output from the counter feeds a conventional amplifier discriminator and rate meter. The scintillation counter is normally operated at a potential of 950 volts.

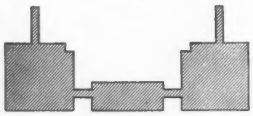
The precipitation chamber, like the rotary switch, is designed to operate at gas pressures of 100 p.s.i. The precipitation equipment comprises a number of motor-driven Tufnol pulleys carrying a wire of 0.005 in. diameter, maintained at a potential of 4 kV. The motor is mounted externally to the chamber and the shaft led through the wall via a drive pressure seal. Solid fission products formed in the chamber or carried in the gas are precipitated on to the wire, which moves in steps corresponding to movements of the selector valve to present the wire to the scintillation counter. The half lives associated with daughter products cover a wide range and it is necessary that a time delay of tens of minutes be provided between successive presentations. A further complication to the design is the necessity for screening the scintillation counter from the bulk of the gas (as counting and precipitation for a succeeding count occurs simultaneously) without the introduction of additional bearing surfaces which would cause an arbitrary amount of wiping.

Longer-lived fission products slowly contaminate the chamber but, due to the low activity of the gas, maintenance is not difficult and wires can readily be replaced and chamber walls cleaned.

In addition to the eight chambers monitoring the channels grouped into fours with a cycle time of 30 minutes, provision is made for selecting any individual channel for special attention. Other chambers are provided which continuously monitor in order the four quadrants at the top and bottom of the reactor and serve to give a continuous bulk reading of the fission product activity in the four coolant circuits. It was felt that this was advisable in case a sudden fault should develop immediately following the monitoring of one group of four, which would then remain undetected for a full cycle period of 30 minutes.

Rarely, however, will faults occur except with a long-time constant associated, and normal operation should see the activity in one group of four slowly rise, the individual channel selected by progressively blanking off each in turn, this channel then being followed continuously on the spare chamber and on a large-scale recorder. At an appropriate level of activity steps would be taken to shut-down the reactor and change the elements in the offending channel.

The rate meter circuits are fitted with appropriate tolerance switches which give visual indication when the background level is exceeded. Further interlock circuits give warning if the flow in any of the channels stop or chamber pressures reduce, potentials disappear, etc. Modern operational philosophy regards a correct functioning of the burst-slug detection gear as vital to the operation of the reactor and it is probable that any major fault in the burst-slug detection gear, necessitating a shut-down, would decide the operations officer to shut-down the reactor itself. A high standard of engineering is therefore necessary throughout.



Heat Exchangers

THE heat exchangers were designed and manufactured by Babcock and Wilcox Ltd., and, apart from the reactor itself, represented the most noteworthy departure from standard power-station practice. The problems concerned with the steam plant fell naturally into four stages:

(1) Formulation of the general parameters for a thermodynamic cycle to give optimum overall efficiency in both power and plutonium production.

(2) The application of these parameters in terms of a practicable design of heat exchanger.

(3) The translation of this into a practical arrangement of tubes and piping, taking into account the additional requirements not met with in conventional steam-raising practice, and the limitations of materials and manufacturing techniques.

(4) Actual manufacture and erection of the plant. These two have been considered together since they were interdependent.

The Steam Cycle

The investigation of the steam cycle for Calder Hall did not present any completely unfamiliar aspect, since a design study of steam-raising plant for a gas-cooled reactor had already been undertaken by the Babcock organization at the request of the Ministry of Supply as far back as 1947. The design problems lay, of course, in the selection of upper and lower temperature limits for the coolant gas to obtain the optimum result from a number of interdependent variables. For example, the plutonium production of a given reactor is proportional to its thermal output so that, from this point of view alone, the optimum conditions indicate a high output temperature and a low input temperature of the coolant. This, of course, would also give a comparatively low flow rate of the coolant and, hence, reduce the blower power required.

On the other hand, even those engineers who are not familiar with boiler design will realize that, from fundamental principles, the saturation temperature (and, therefore, the steam pressure obtainable) is set by the temperature of the gas leaving the heat exchanger, i.e., the low temperature side of the reactor.

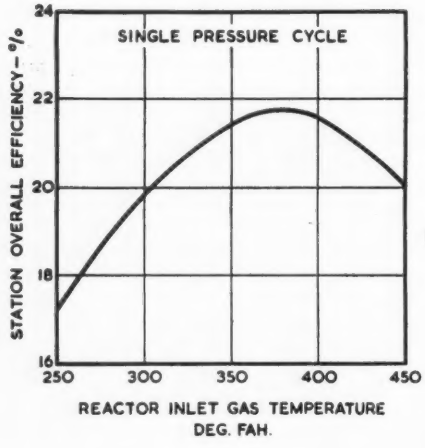


Fig. 1 (left). Efficiency of single pressure steam cycle.

Fig. 2 (right). Comparative efficiencies of double and single steam cycles.

Here, then, are two mutually opposed factors. A low gas temperature will not give us economical steam generation, due to the low pressure and consequent low heat drop available for the turbines. Raising the "low" temperature will improve steam conditions, but will need a greater mass flow and consequent increase in blower power to give the same reactor cooling effect.

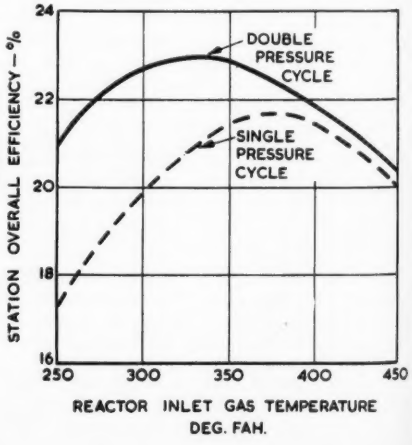
The results of a great many calculations, allowing for practical considerations (such as the necessity for providing sufficient superheat to ensure reasonable dryness of the steam at the turbine exhaust), shows that the overall efficiency (Fig. 1) reaches a peak at about 375-400°F less than 22%.

Dual-pressure Cycle

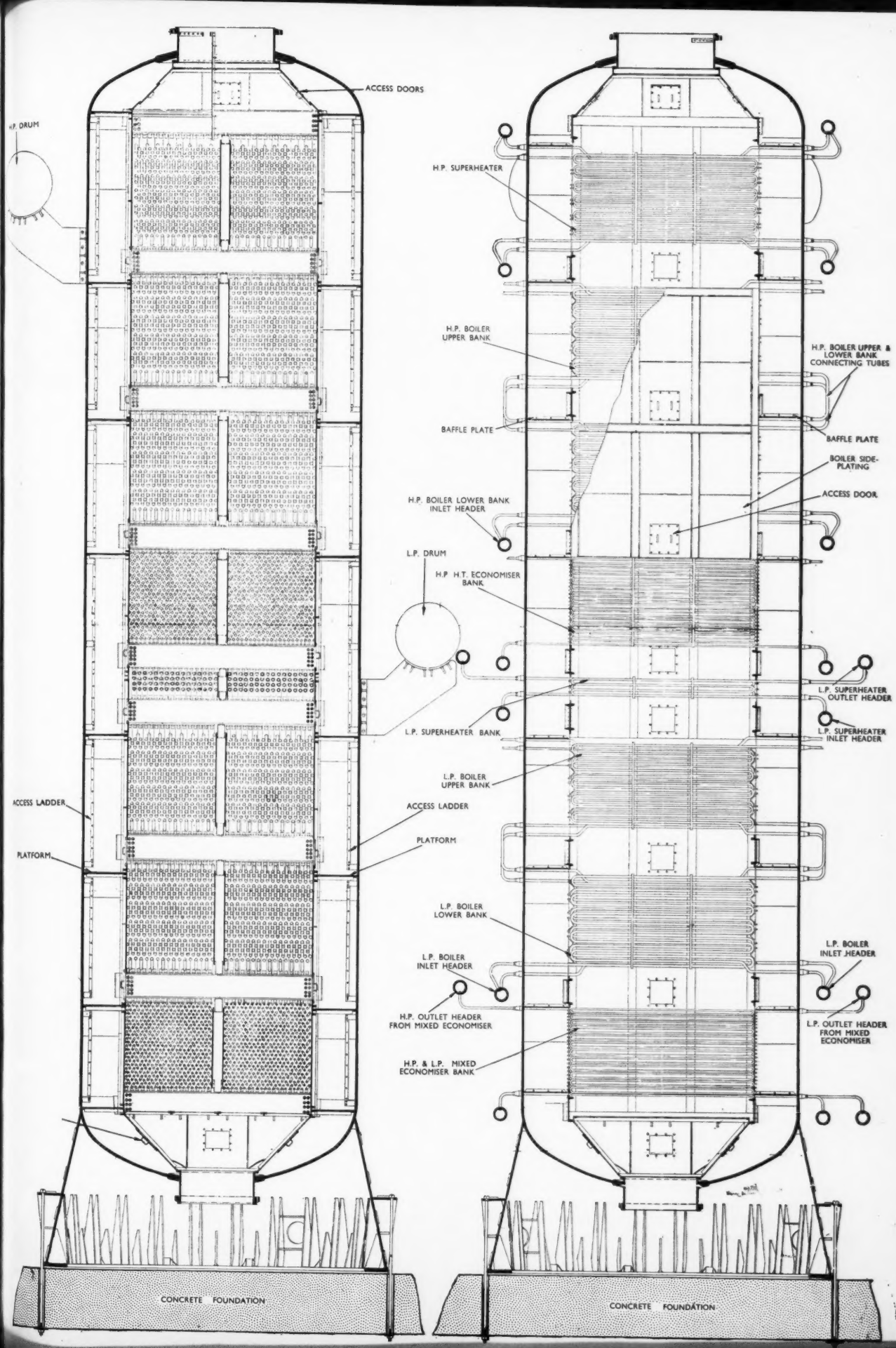
A method of obtaining improved efficiency, which had already been investigated some eight years ago, was the possibility of using a dual-pressure cycle, using part of the heat drop in the circulating gas to generate steam at a high pressure, and the remaining heat in a low-pressure system. Saturation temperature in the H.P. system is then not tied down to the "low" temperature of the gases, but can be fixed at a convenient intermediate point. Similarly, the L.P. system can be designed economically to work down to a lower "cool" temperature.

It must, of course, be borne in mind throughout that it is not possible to increase output by raising the temperature of the gas leaving the reactor, this being limited by the allowable maximum temperature of the hottest fuel elements. The increase in efficiency obtainable can be seen from Fig. 2.

An additional advantage of the dual-pressure is that it can be used to control temperature conditions at the reactor, since, at any given load on the plant, the temperature of the gas leaving the heat exchanger depends upon the pressure in the L.P. sections. If the reactor is operating at part load, gas temperature would be lower, which might introduce undesirable temperature changes in the reactor. By throttling the L.P. steam, the tube surface temperature of the L.P. section is raised, and prevents the gas temperature from dropping.



The optimum conditions for plutonium production do not necessarily coincide with those for efficiency on the steam side. For a given minimum capital expenditure, the pluto-


ACCESS DOORS
H.P. DRUM
H.P. SUPERHEATER
H.P. BOILER UPPER BANK
H.P. BOILER UPPER & LOWER BANK CONNECTING TUBES
BAFFLE PLATE
BAFFLE PLATE
BOILER SIDE-PLATING
ACCESS DOOR
H.P. BOILER LOWER BANK INLET HEADER
L.P. DRUM
H.P. H.T. ECONOMISER BANK
L.P. SUPERHEATER OUTLET HEADER
L.P. SUPERHEATER INLET HEADER
L.P. SUPERHEATER BANK
L.P. BOILER UPPER BANK
ACCESS LADDER
ACCESS LADDER
PLATFORM
PLATFORM
L.P. BOILER LOWER BANK
L.P. BOILER INLET HEADER
L.P. BOILER INLET HEADER
H.P. OUTLET HEADER FROM MIXED ECONOMISER
L.P. OUTLET HEADER FROM MIXED ECONOMISER
H.P. & L.P. MIXED ECONOMISER BANK
CONCRETE FOUNDATION
CONCRETE FOUNDATION

nium output increases considerably with a reduction in the low-side gas temperature, whereas the steam output may be reduced.

For example, a certain reactor with a low-side gas temperature of 356°F would give 145 MW total output, a net thermal efficiency of 27% and 39 MW electrical output. Lowering the low-side gas temperatures to 212°F gives 213 MW output without increase in fuel element temperature, and an electrical output of 41 MW, although the net thermal efficiency will be only 19%. The amount of plutonium produced being proportional to the thermal output, the second case will give nearly 50% more plutonium, plus a slight increase in the electrical output.

An extensive study was carried out on the dual-pressure cycle, including variations of the pressures, the proportions of steam generated at each pressure, the feed temperature, the cooled gas temperature, the amount of heating surface in the heat exchangers and the pressure loss in the gas circulation. Other cycles studied included dual-pressure steam cycles with reheating and triple-pressure cycles with and without feed heating, reheating and thermocompression. While some of these showed considerable theoretical advantages, the practical difficulties outweighed them. Reheating, for example, increases efficiency, but this is largely offset by increased pressure drop in pipe-work. In general, it was considered preferable to keep Calder Hall, the prototype plant, as simple as possible.

The conditions finally decided upon at Calder Hall employed a dual steam cycle to give an electrical output of about 40 MW per reactor with gas temperatures of 638°F and 285°F, the corresponding steam pressures being 200 p.s.i. and 50 p.s.i. with 77% of the power generated at the high pressure. The coolant flow is approximately 7,000,000 lb./hr.

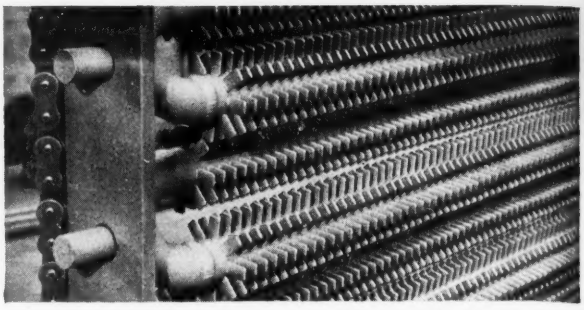
Application of Studies

Having settled the thermodynamic parameters of the scheme, the next step was to turn it into a practical design, and most of the problems lent themselves to solution by conventional steam engineering methods. In effect, it was necessary to design a furnaceless boiler system fired by hot gas after the fashion of a waste-heat boiler, with two noteworthy exceptions: first, that the gas temperature was much lower than that normally associated with conventional boiler plant and, second, that the gases were perfectly clean with no corrosive fumes, no deposit-forming smokes, and no softened fly-ash, so that it was practicable to use extended tube surfaces. Nevertheless, even with extended surfaces, low temperature demanded a very large heating surface.

Other considerations, of course, arose. Paramount was the question of safety in operation. It was essential that any leakage of steam into the cooling gas and vice versa would be impossible. Double-tube construction was ruled out on account of cost and excessive bulk. The design chosen was a shell-and-tube type representing a combination of straight steam boiler and oil refinery practice.

Since the plant had to be manufactured in Scotland and transported to Cumberland, practical considerations dictated the subdivision of the steam-raising units and the single heat exchanger became a group of four for each reactor, thus bringing the units to a size which could be dealt with by conventional methods. The design proposed consisted of an outer shell or tower, through which the gases were circulated. To minimize the possibility of leakage of steam into the gas or gas into the steam the heating surface was arranged in multi-loop cross-flow units which are inherently flexible and have an almost complete absence of expansion stresses. (Other precautions against leakage are dealt with in a later section.) The use of multi-loop cross-flow elements allowed the use of extended heating surface which, owing to the absence of solid deposits in the circulating gas, were eminently suitable for this duty. This gave a possibility of quadrupling the effective tube surface.

As finally settled, each heat exchanger or steam tower consisted of tube banks constituting H.P. and L.P. boiler sections, H. P. and L.P. economizer sections and H.P. and L.P. superheaters.



Part of tube section, showing oval studs.

Practical Design

The translation of these working data into a practical design which would satisfy requirements for manufacture, transport, erection and servicing involved many other considerations. The pressure shells resembled oil-refinery vessels, and the tube banks were proportioned so that any element could be withdrawn through the gas inlet opening at the top. Ample access space is left between the tube banks and the pressure shell and a narrow vertical passage is left in each tube bank through which faulty elements could be removed and replaced without having to cut out large numbers of sound tubes.

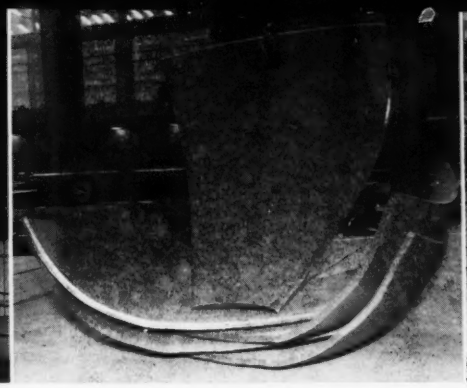
It was laid down as an essential that any joints, where there could be even a remote possibility of leakage of steam or water occurring, must be located outside the pressure shell, and this was done by carrying both ends of each individual element through the shell of the pressure vessel and making connections externally. Should leakage ever occur at the junction of tube and shell, gas would escape to atmosphere and not, for example, into the low-pressure steam system, while any leakage taking place at the junctions of tubes and headers would result in steam or water escaping to atmosphere and not contaminating the gas. All tubes at the points where they penetrate the pressure vessel are carried in thermal sleeves to minimize temperature stresses at these points.

For the extended surface, studs are attached by welding to the tube surface. The studs are of elliptical section to minimize pressure drop in the coolant circuit, and tubes with the actual pattern of studs finally adopted were subjected to exhaustive tests for heat transfer and pressure-drop characteristics. The actual attachment of the studs to the tubes by semi-automatic resistance welding was a well-known process, since with plain, round studs it has been used for some years on boiler work, particularly in the marine field, and it was known not only that sound welds, having a constant thermal bond, could be produced, but that they could be produced in very large quantities if required—a very necessary requirement, since each of the eight heat exchangers for Calder Hall "A" called for nearly 11 million studs—a total of 85,000,000 for the complete station.

Particulars of the heat exchanger tube surface (external) are as follows for each heat exchanger.

	Elements in parallel	*Total heating surface*
H.P. superheater	64	4,700 sq. ft.
L.P. superheater	32	785 sq. ft.
H.P. evaporator	64	31,500 sq. ft.
L.P. evaporator	64	31,500 sq. ft.
Economizer	84	31,500 sq. ft.
		99,985 sq. ft.

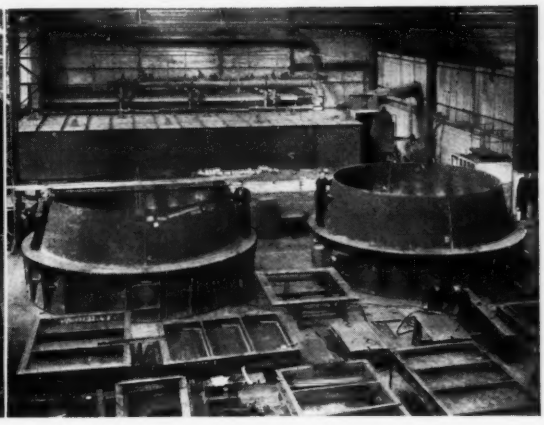
Hot-pressing plates for end domes on 2,000-ton press.



Shaped plates after pressing.

Welding end domes.

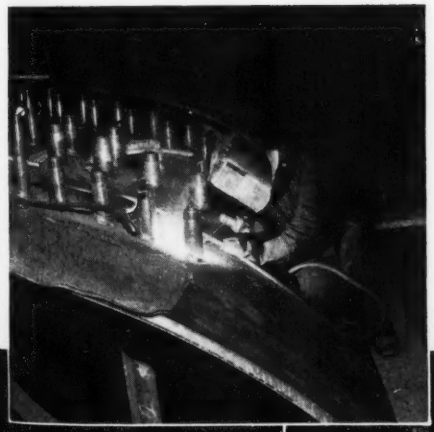
Shell sections under construction.



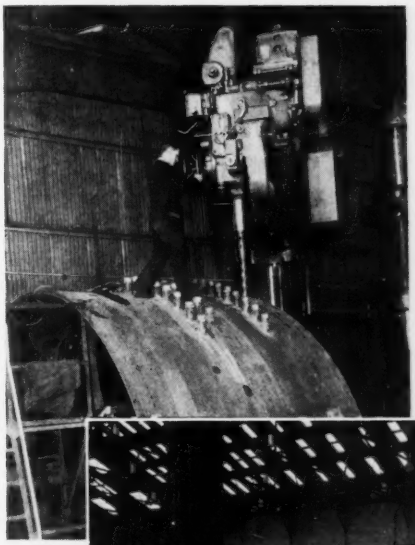
Fabricating base skirt.

AT THE WORKS

(Photographs by courtesy of Babcock and Wilcox Ltd.)



(Left) Welding thermal sleeves to shell.



(Right) Drilling thermal sleeves.

(Extreme left) Semi-automatic resistance welding of studs.

(Left) Gas welding return bends to tubes.

(Right) Hydraulic testing of

Both H.P. and L.P. superheater sections use plain tubes: all others are studded. Tubes used, of which there are more than ten miles in each heat exchanger, are of the ERW type manufactured by Stewarts and Lloyds Ltd. and are 2 in. and $1\frac{1}{2}$ in. in diameter.

Circulation

The parallel connection of tube sections is carried out by means of external headers. A separate steam and water drum is provided for both high- and low-pressure boiler sections. These drums are 4 ft. diameter and 18 ft. long and contain "cyclone" steam separators of conventional design. The evaporator sections operate with forced circulation, both H.P. and L.P. sections being fitted with circulating pumps giving a circulation of about four times the steam output of the section. These pumps are of the "drowned" or glandless pattern manufactured by Hayward Tyler and Co. Ltd. Standby pumps were provided by Mather and Platt Ltd.

Manufacture and Erection

The dimensions of the heat exchanger precluded any possibility of fabrication and dispatch to site in one piece, and the diameter was chosen to enable the largest possible sections to be transported, thus involving a minimum of site assembly. Nevertheless, it was necessary to dispatch each tower in ten sections, comprising six sections of the shell, the two domed ends and the two halves of the base. The dimensions of the shell are approximately 80 ft. × 18 ft. diameter.

Shell

The shell sections were fabricated from "Coltuf 28" rolled plate, manufactured by Colvilles Ltd., $1\frac{5}{16}$ in. thick, with the longitudinal seams fusion-welded by the metallic arc multi-layer process. Class 1 welding was specified throughout and all welds were subject to normal boiler-drum examination, including X-ray photography of all welds (and routine mechanical tests on test pieces). The large diameter of these shell sections caused them to be unusually flexible and practically all operations in the shops were carried out in the horizontal position; distortion was prevented by a temporary stiffening framework of angle iron inside each section.

The domed ends were fabricated from a number of segments formed in a heavy hydraulic press and the segments were afterwards welded together and the edges machined on a boring mill. All nozzles, branches and thermal sleeves, etc., were affixed at the works and each unit was stress-relieved in a large furnace.

Upon arrival at site the sections were loaded on to special bogies on a rail track leading into a site workshop specially built, with duplicate tracks so that two vessels could be worked on at the same time. The bogies were provided with rollers, which supported the vessel sections in a horizontal position and enabled them to be rotated for the circumferential seams to be welded in a down-hand position throughout.

Class 1 welding was, of course, required, as was a high standard of accuracy, not only in the shell itself but in the positions of the many attachments. Each weld was radiographed upon completion.

Stress-relieving of each circumferential seam was carried out by induction heating, with an insulating lagging surrounding the seam and the inductor coil. A 2,500 c/s supply was used for the source. The equipment was developed by the Electric Furnace Co. Ltd., and the generator had an output of 200 kW, giving a temperature of 630°C in three hours.

The completed pressure vessels were taken outside, jacked off the bogies and supported instead on heavy sections of timber. All openings were sealed and the vessels filled with water and hydraulically tested to more than $1\frac{1}{2}$ times working pressure. After emptying, and meticulous cleaning by shot-blasting, they were sealed before transporting to their final position on the site.

Tube Elements

The tube was received in straight lengths. Studding was the first operation, and this was carried out in a battery of semi-automatic spot-welding machines which simultaneously affix two studs on opposite sides of the tube. The movement of the welding arms, the pressure and the timing are all automatically controlled; the studs, however, are loaded into the slots on the arms by hand. The machines are fitted with long beds carrying moving carriages advanced by air cylinders and controlled by a pawl on the carriage moving along a stationary rack. After each operation the pawl is released and the carriage moves up one notch on the rack in position for the next pair of studs. On the completion of the two rows of studs the carriage is withdrawn and the tube rotated through an angle to commence the next two lines.

Sections are formed from the tubes by the welding on of return bends, acetylene welding being used for this operation. They were then submitted to pressure and vacuum tests, and meticulously cleaned by shot-blasting.

Upon arrival at site any traces of rust formed in transit or storage were removed by shot-blasting, a process which was carried out with the utmost thoroughness. Each section was then put into a special container to protect it from subsequent contamination. On the top of each heat exchanger shell a temporary house had been erected to act as a "dirt lock" for the main entrance—coolant inlet—to ensure that nothing in any way dirty entered the shell. The erectors were required to wear special clothing and air conditioning of the inside of the vessel guarded against moisture, the air being filtered through dryers manufactured by Silica Gel Ltd.

Testing

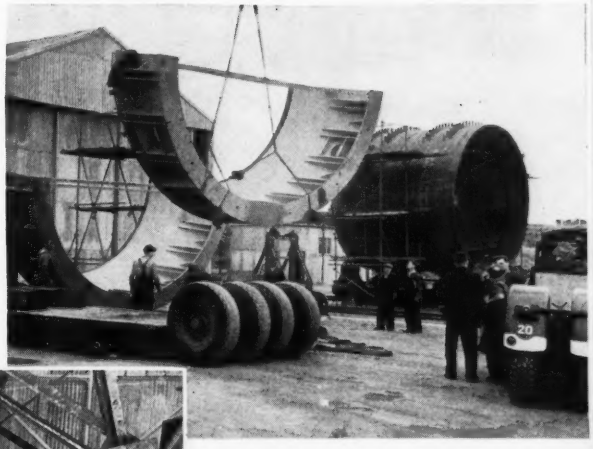
Tests already carried out during manufacture and erection included, in addition to the normal X-ray and pressure tests, gas testing of the thermal sleeves using an infra-red gas analyser, the tube sections being vacuum tested in an atmosphere of hydrogen. Final tests after erection included gas tests using a leak detector.

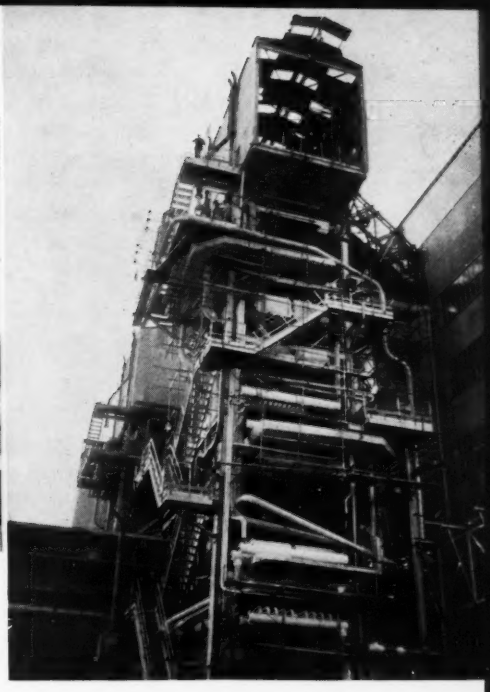
If, in spite of these stringent precautions, any porosity might conceivably occur, its detection would be relatively simple. Sensitive humidity meters in the outlet ducts would indicate any leakage of steam into the coolant, and the complete heat exchanger would be isolated from the gas circuit by closing the valves on the inlet and outlet ducts. The steam side would be similarly isolated and emptied of water. Then, since the coolant side is still pressurized, the porosity would cause a leakage of gas into the steam side, which can be detected by gas-analysing probes. This tracing would, of course, be simplified by the design of the external tube connections, which incorporate headers with the usual removable covers. Having traced the faulty element, it could be cut and capped external to the vessel, capping being carried out by welding. The exchanger could then go back into service with an idle element—the gas temperature is not high enough to cause overheating as would occur with a normal boiler. There is, therefore, no need whatever to open up the exchanger or to go inside it.

General

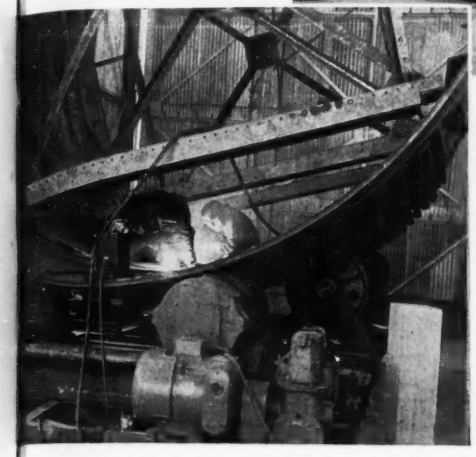
Since the equipment is for outdoor service, all of the auxiliary equipment is designed to suit adverse weather conditions. The units are, of course, heavily lagged for thermal purposes (Darlington) and finished with waterproofing compound. Dewrance boiler mountings are fitted, and there is an extensive system of galleries and ladders supplied by Edwin Danks and Co. (Oldbury) Ltd. Boiler mountings including parallel slide valves for the steam and feed lines, etc., were supplied by Dewrance and Co. Ltd., the water gauges being of their Bi-Colour type. Weir feed regulators were used on both H.P. and L.P. drums.

(Below) Welding shell sections together.





Heat exchanger almost completed.

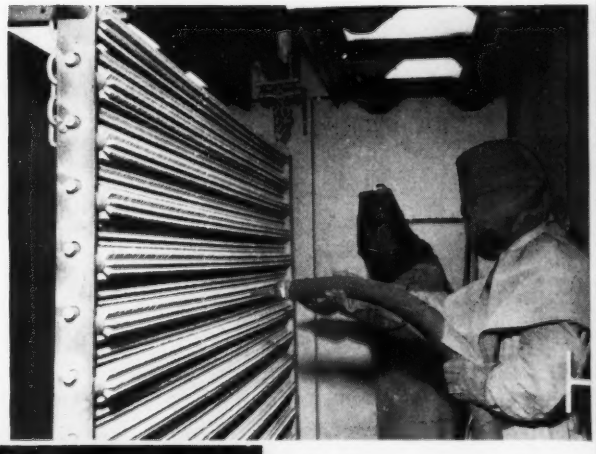


Unloading section of base skirt.

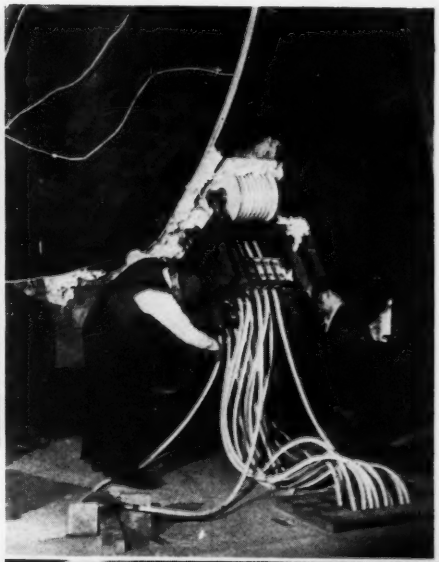
ON SITE

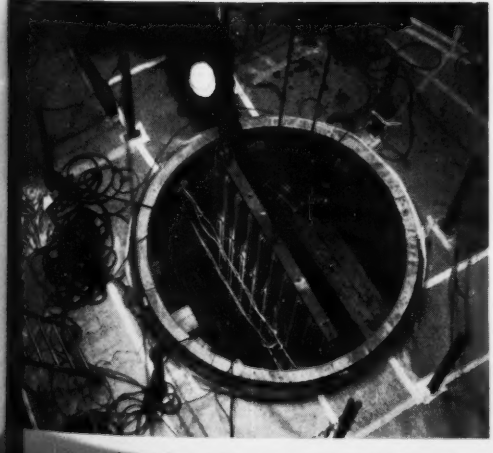
(Photographs by courtesy of Ace Distributors Ltd.)

Shot-blasting tube sections.



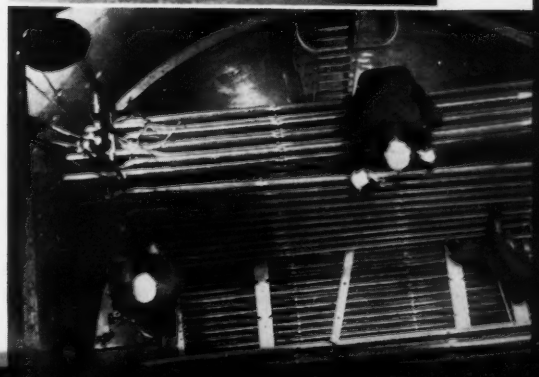
High-frequency heating for stress-relieving shell joint.

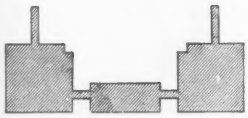




(Left) Lowering complete section through the gas inlet.

(Right) Assembling tube banks inside the heat exchanger.





Coolant Gas System

THE main flow of coolant gas is shown in the accompanying schematic diagram and, in greater detail, on the pull-out next to page 296.

Each heat exchanger is associated with an independent gas circuit, there being only one common point, at the reactor inlet, for all four circuits. To simplify shielding, the ducts are not equally spaced around the reactor at right angles, but make angles of 70° and 110°. It might be thought that uneven distribution of gas would result; this, however, is not the case, since the pressure drop in the reactor is considerably higher than that of the rest of the circuit, which should ensure reasonable uniformity of flow; but fine adjustment can, of course, be effected by manual trimming of the blower speed.

Blowers

There are two main blower houses, each serving two heat exchangers and containing the blowers and their ancillary equipment such as filters, cyclones, oil tanks and oil pumps.

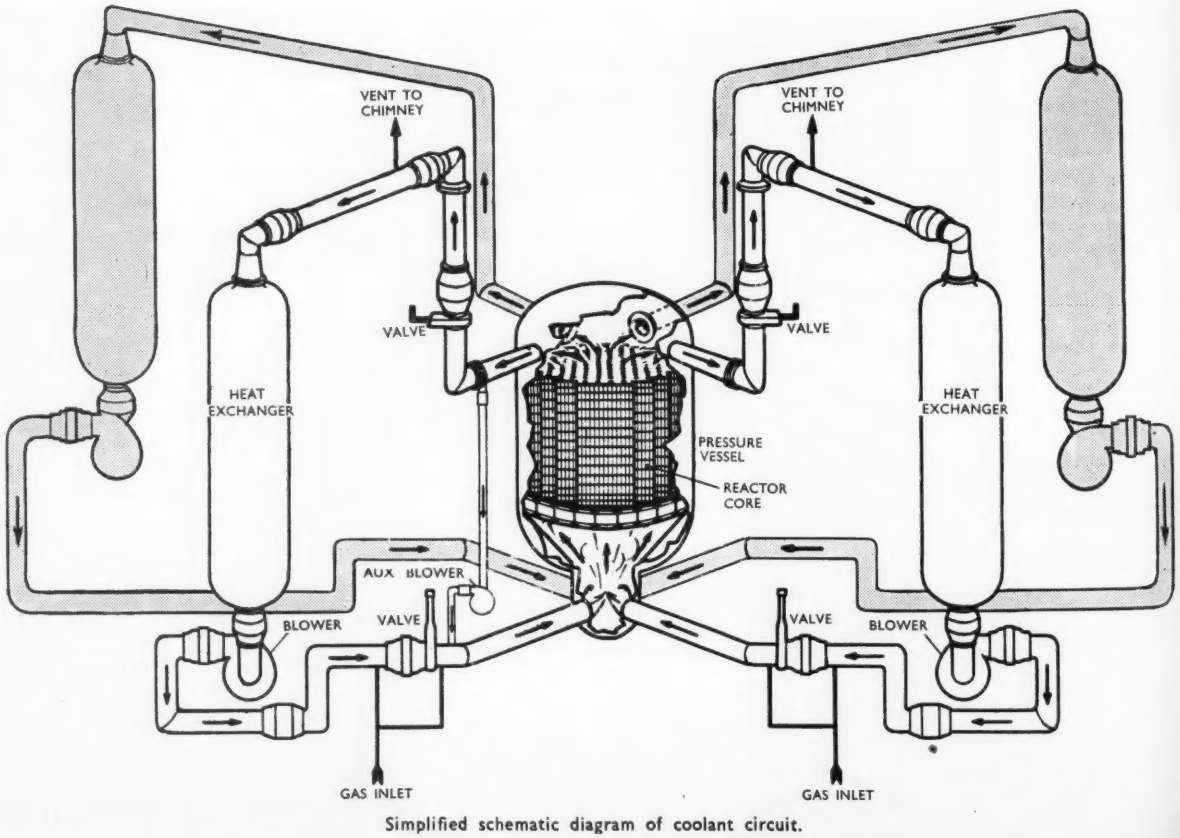
It was decided during the design stage that the control of the mass gas flow would best be carried out by varying the blower speed, rather than changing the pressure of the system. A wide speed variation (10-1) was decided upon, although this may prove to be unnecessary. In the circumstances, Ward-Leonard drive seemed the best choice.

The blowers, manufactured by C. A. Parsons Ltd., are of the single-stage centrifugal type with an overhung impeller, this having the advantage of requiring only one bearing and gland, and considerably facilitating maintenance without danger from radiation.

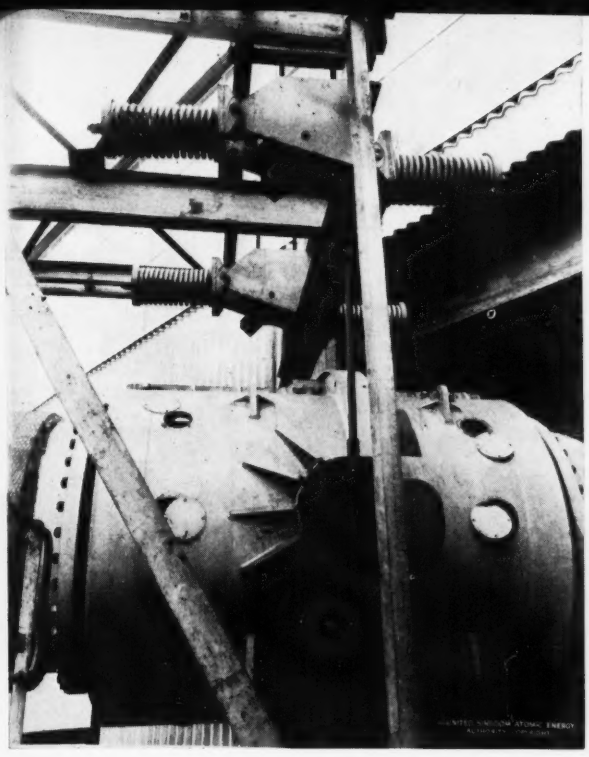
One of the most important requirements was to obtain minimal leakage, and a packed gland or conventional labyrinth was not considered suitable. Experience with the sealing of hydrogen-cooled alternators enabled a satisfactory arrangement to be evolved. "Bulk" sealing is provided by a face-labyrinth seal with concentric rings attached to discs; the small amount of leakage passes into a chamber maintained at a slightly lower pressure. Into this is fed the leakage from an oil seal at a higher pressure, and the resulting oil-gas mixture taken away and separated.

A further requirement was for the running seal to be capable of inspection or removal whilst under pressure, and a "standstill" seal was incorporated between the labyrinth gland and the impeller.

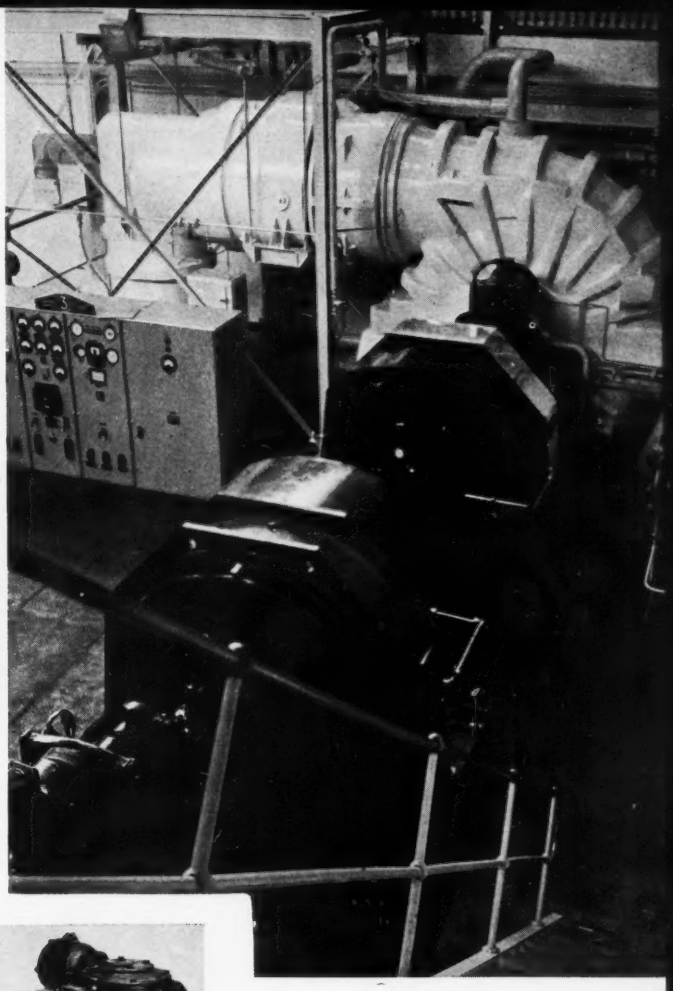
The blowers have a normal capacity of 1,964 lb./sec. at 284°F and 100 p.s.i. The main driving motors are by Mather and Platt Ltd., and are rated at 1,500/2,200 h.p. at 854/940 r.p.m. In an emergency, operation at very low speeds is possible by the use of a pony motor rated at 10/100 h.p., geared to the shaft through a Sinclair clutch to



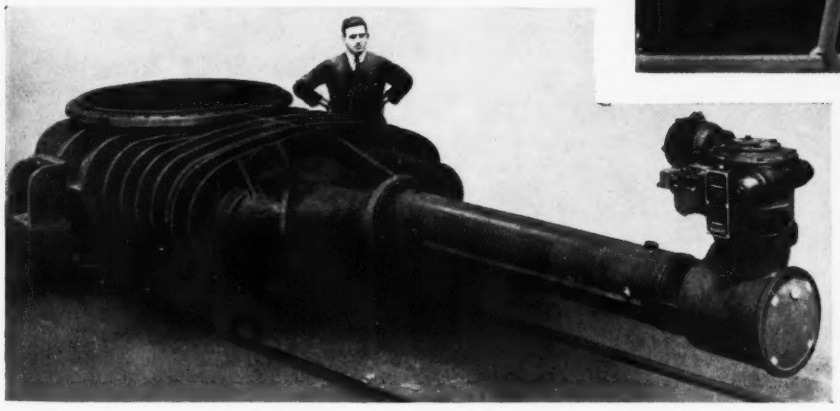
Simplified schematic diagram of coolant circuit.



A bellows assembly in the main gas duct, supported on Vokes Genspring supports.



One of the main Parsons blowers with Mather and Platt driving motor.



One of the Blakeborough 54-in. motor-operated valves for the main gas circuit.

prevent the pony motor being run overspeed by the main motor.

The Ward-Leonard motor generator sets are also of Mather and Platt manufacture, each consisting of an 11-kV, 2,500-h.p., three-phase induction motor with a speed of 750/742 r.p.m. and a generator rated at 1,730 kW at 540/600 V.

Remote-control gear in the control room enables speed changes to be carried out simultaneously on all four blowers, and Record electric tachometers are located in the blower room and in the main control room.

All four units have an auxiliary circuit connected across the blower system, about 2% of the gas being extracted passed through cyclones and returned to the low-pressure side of the circuit, the object being to prevent any accumulation of graphite dust or iron oxide. There is also an auxiliary blower unit connected directly across the pressure vessel, for partial circulation should the main system be shut down.

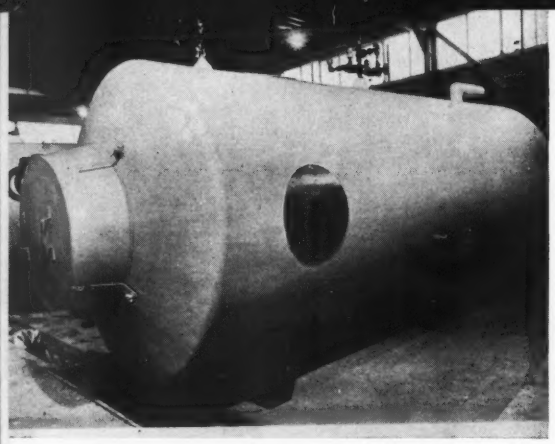
Duct-work

The ducts are of mild steel, circular in cross-section, 4 ft. 6 in. in diameter. They were fabricated to Lloyd's Class I specification by Robert Jenkins and Co. Ltd. from $\frac{3}{8}$-in. plate, the total length supplied being 1,500 ft. and the weight 300 tons. Internal cascade vanes are fitted at the bends.

Where they pass through the biological shield a steel sleeve is provided, the duct being held concentric within the sleeve by means of a spider. Cooling air is forced through the annular space to prevent the heat being transmitted to the concrete shield.

As may be imagined, the expansion in a system of this type requires generous allowances. Linear expansion has been taken care of in a conventional manner by the avoidance of rigidly-anchored straight runs. From the heat exchangers to the blowers and from the blowers to the reactor vessel the layout of the ducts allows for expansion loops. Bellows-type expansion joints are used where sections of ducts are joined together. Bearing in mind the size of these ducts and the operating pressure, it is obvious that free bellows cannot be used. The bellows are of steel, bolted to heavy flanges, and each has a housing with hinge pins of generous design. For angular movements in more than one plane, a gimbal ring housing is used.

As can be seen from the diagram, valves are provided in two positions on each main duct circuit, so that any heat exchanger or blower requiring inspection can be readily isolated. These valves are of the wedge-gate type manufac-



Lagged liquid CO_2 storage tank manufactured by John Thompton Ltd. for the Carbon Dioxide Co.

tured by J. Blakeborough and Sons Ltd., and have a number of interesting features. In addition to the size (54 in.), the working temperature is unusually high for the size and absolute freedom from leakage is required with very limited access during the life of the plant.

Of the outside-screw type, the valves have cast-steel casings and gates and monel metal face rings and seats. The stem and rising spindle are of aluminium bronze.

Tests during manufacture included radiographic examination of all pressure castings, hydrostatic tests on casing and gate, seating tests under compressed air and operating and tightness tests at 700°F.

Half of the valves were arranged for vertical mounting and half for horizontal; all were arranged for motor operation and remote control and indication. The operating time is about 2¼ min. in either direction.

Other valves, up to 8 in. in diameter, were supplied by Dewrance and Co. Ltd., who also provided Dewrance-Consolidated relief valves of the high-lift, high-capacity type.

In view of the weight of the ducts, the heavy valves and the bellows joints, particular attention had to be paid to the question of support, without transmitting varying loads and bending forces to the reactor or the heat exchangers, and constant support hangers were used to guard against this. These are of the "Genspring" type, manufactured by Vokes Genspring Ltd., which automatically compensate for variations in spring tension. Some of these represent the largest units yet built in this country.

The duct-work is lagged by Darlington Insulation Ltd. in the same way as the heat exchangers.

Gas

The original intention was to use solid CO_2, but it was later decided that the liquid form would offer advantages in ease of handling and in purity, eliminating the entrapment of air inevitable during recharging of a converter with solid material. The liquid CO_2 is supplied by the Carbon Dioxide Co., a division of the Distillers Co. Ltd., who also supplied the storage plant and evaporator equipment. There are four tanks with a total capacity of 22 tons, storage pressure being some 300 p.s.i. (0°F). Delivery is by road tanker with a capacity of approximately 4 tons, through a pair of flexible hoses (for pressure balancing before transfer, to reduce pumping power). The storage tanks were made by John Thompson Ltd. and are fitted with refrigeration coils to keep the temperature within the appropriate limits. Metropolitan Refrigerators Ltd. supplied the refrigerating unit. The evaporator equipment, which takes the form of a steam-jacketed pipe system, was built by the Distillers Co.'s research laboratories and insulation for the storage plant was by Dick's Asbestos Ltd.

More than 20 tons of CO_2 was required for the first filling, which was carried out by exhausting to a rough vacuum and then purged by repeated charging and discharging.

Drying of the gas is carried out by "Humidryers" supplied by Burnett and Lewis Ltd. Continuous monitoring of the gas is described under "Burst Slug Detection" (page 286).

Placing the Graphite

THE graphite structure is a 24-sided prism 27 ft. high and 36 ft. across corners and weighs just under 1,150 tons. The actual core dimensions are 21 ft. high and 31 ft. diameter. It is made up of a large number of blocks and 3-in. tiles, perforated by the vertical fuel and control-rod channels and held in place by 11 articulated 24-sided steel restraint rings. The weight of the graphite is taken on the diagrid, which comprises an I-section ring girder spanned by steel members to form a rectangular lattice. Across the diagrid are bolted 4-in.-thick steel base plates having holes in them to coincide with the channels on the graphite. The top surface of these plates is accurately machined to provide an absolutely level and smooth surface. These base plates support the graphite through races, made by Pollard Bearings Ltd., which allow for differential thermal expansion of the diagrid and graphite. Each race comprises 18 ¼-in. balls, and there is one race under each column of graphite.

The graphite was supplied by British Acheson Electrodes Ltd. Because of the large number of blocks involved for all four Calder Hall reactors, it was possible to set up flow-line production. Machining was carried out at Windscale largely on milling machines, these being found best to keep chipping to a minimum. An extensive dust-extraction system was employed.

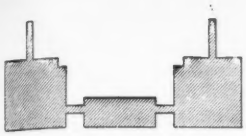
The placing was carried out by Matthew Hall and Co. Ltd. The blocks and tiles arrived packed in cartons and ready coded for order of assembly. A lift took them to the storage areas, arranged on three floors, passing through an airlock to ensure that they were stored under clean conditions. At the storage areas the graphite was unpacked as required and placed on conveyors taking them through one of the 4 ft. 6 in. diameter gas outlets in the pressure vessel. Inside the vessel stages were erected for inspection of the blocks and for loading into skips for lowering into the vessel by a gantry crane.

Clean, dust-free conditions were maintained in the pressure vessel by drawing in filtered air through the base of the vessel and extracting it by means of a fan through one of the apertures near the top. Another extractor fan was arranged to draw away stale air from within the top dome.

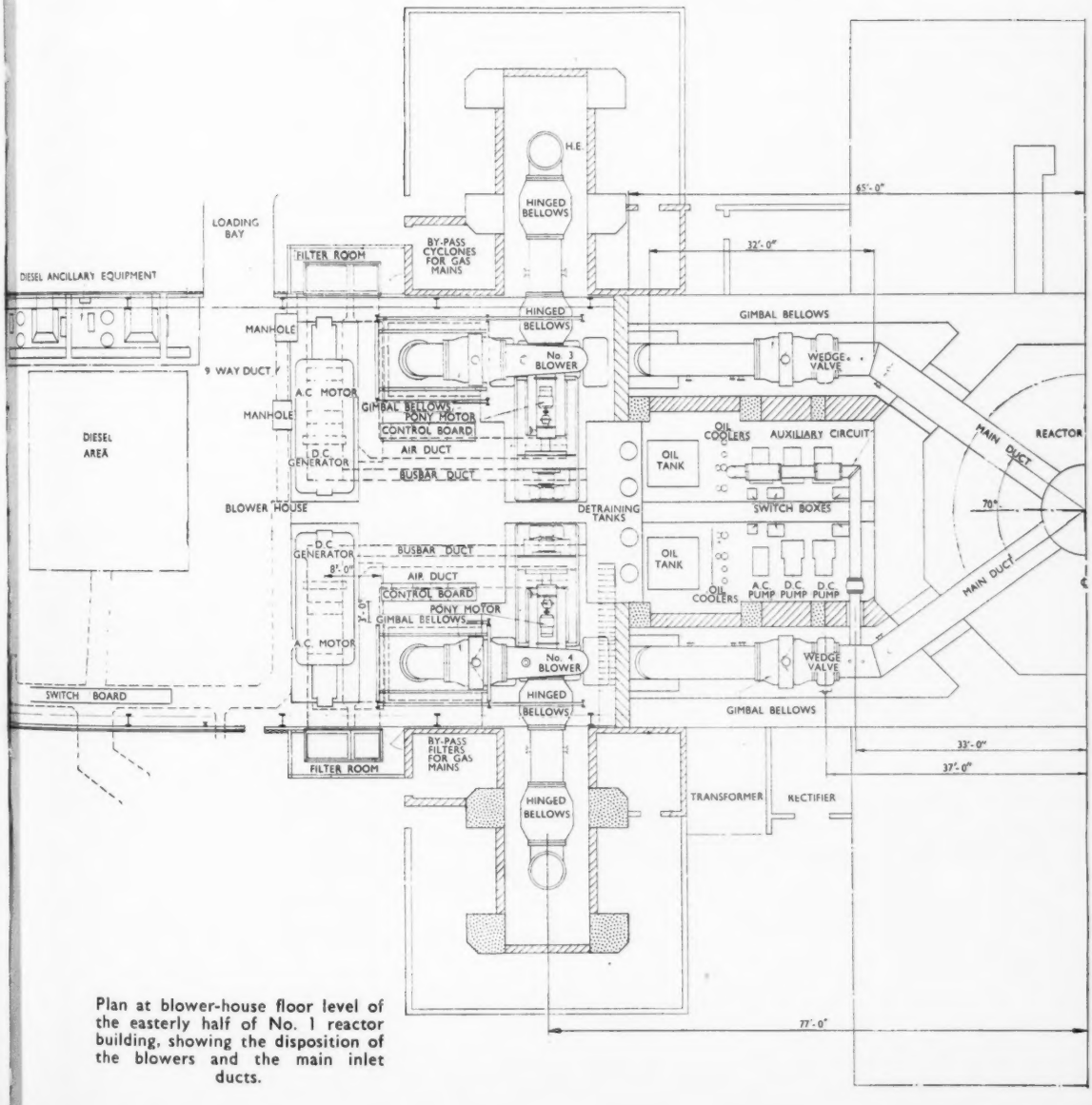
Positioning of the graphite had to be done to very fine limits of accuracy and the placing of the first layer obviously entailed the highest precision. First, straight edges were set up from the centre of the surface bed to form a quadrant and the first four blocks positioned in the right angle. These, with their overlying layer of tiles, were positioned and pressed together by simple hand-operated screw jacks and wooden blocks. When the correct alignment had been achieved, the remainder of the blocks and tiles were placed, row by row, working parallel to one of the straight edges and outward toward the wall of the pressure vessel the jacks being used for clamping as the work proceeded. The other three quadrants were then dealt with in turn.

The graphite core is held by 11 restraint rings or polygons, comprising 24 steel pieces articulated by knuckle joints and tightened by means of a turnbuckle. The first of these restraint rings holds the initial layer of blocks and was tightened to the correct setting before work began on the next layer.

The graphite was then built up in layers of alternate blocks and tiles keying into one another, the appropriate restraint rings being adjusted as the work proceeded.

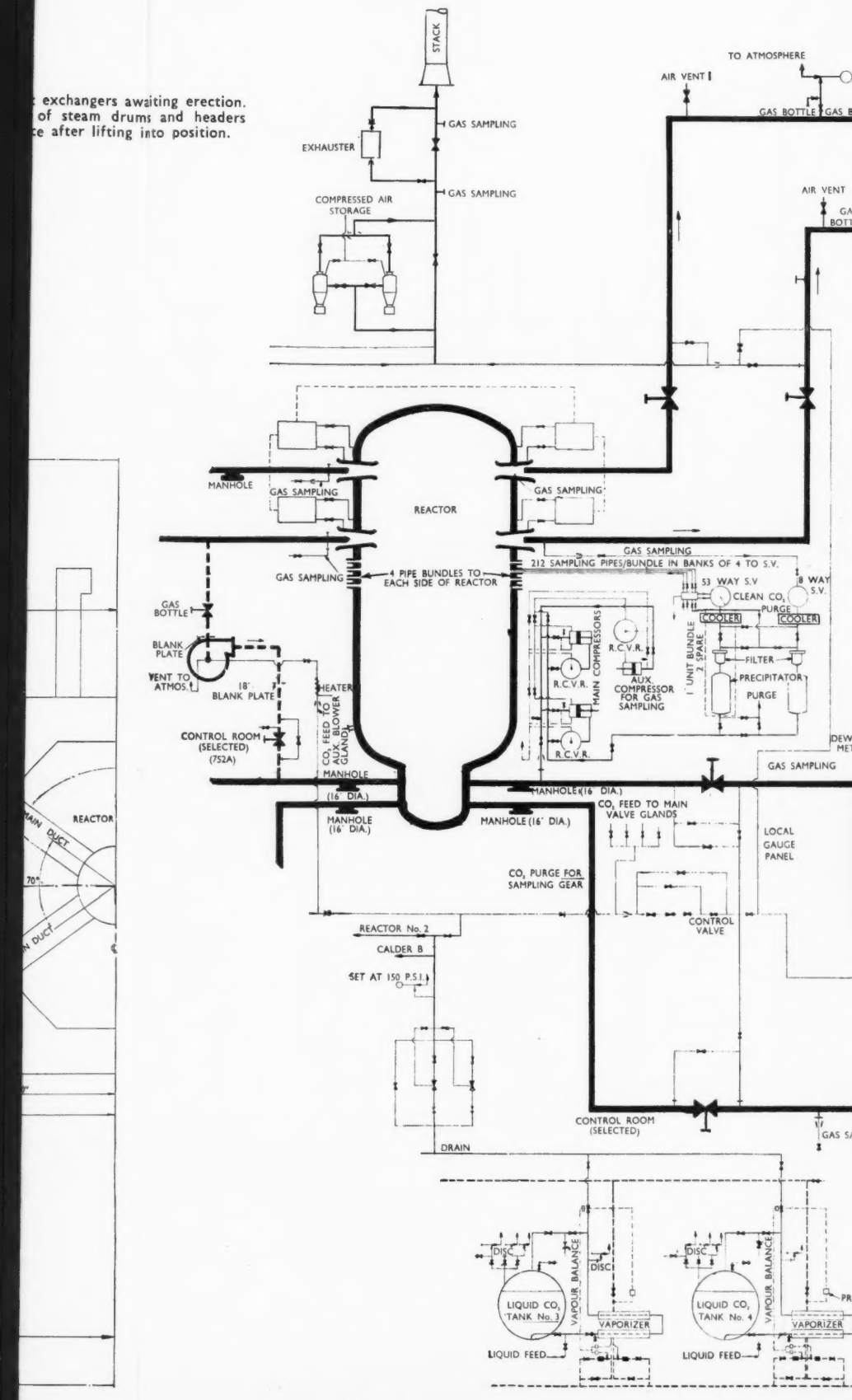


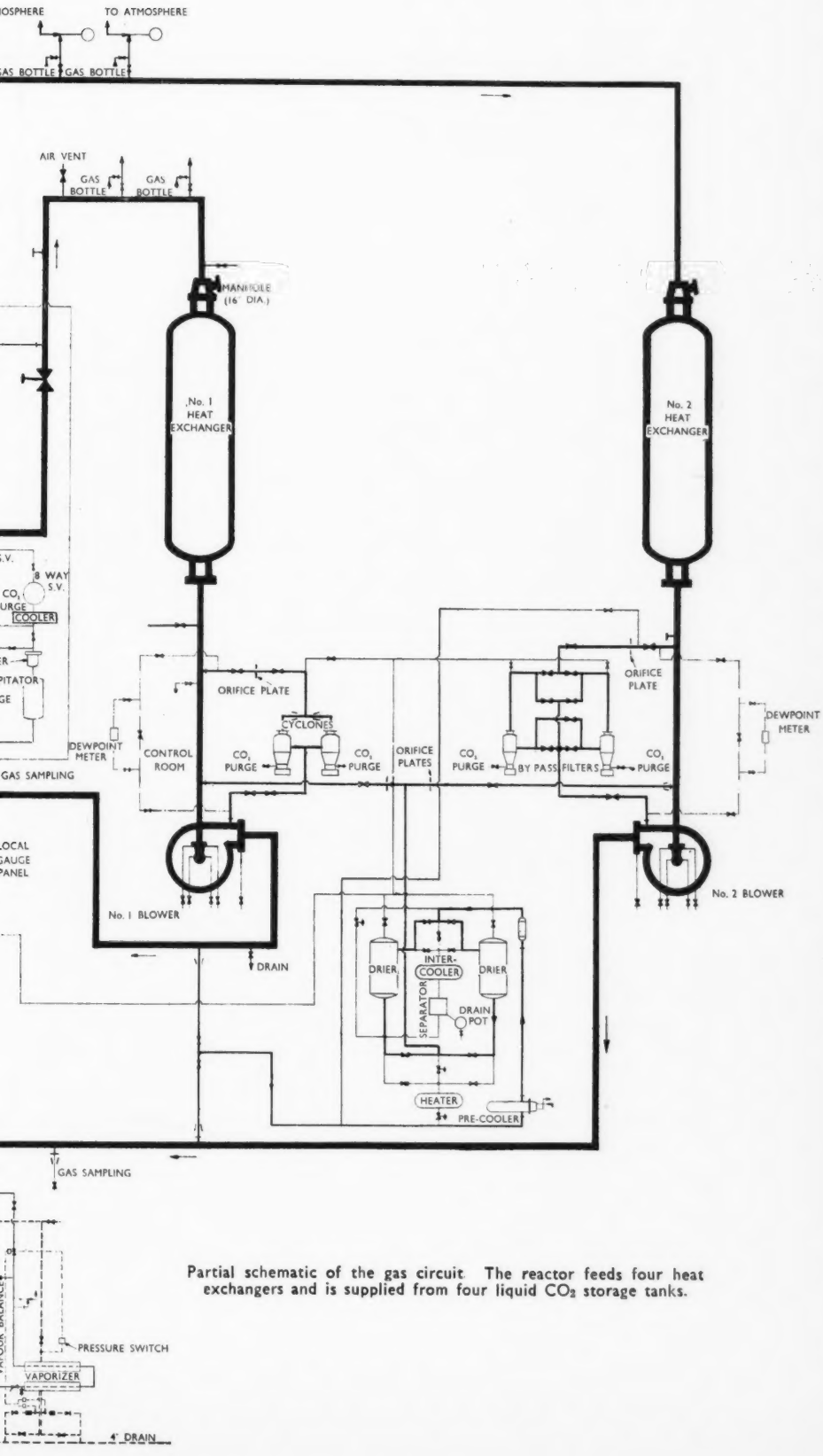
(Left) Heat exchangers awa
Installation of steam drum
takes place after lifting i



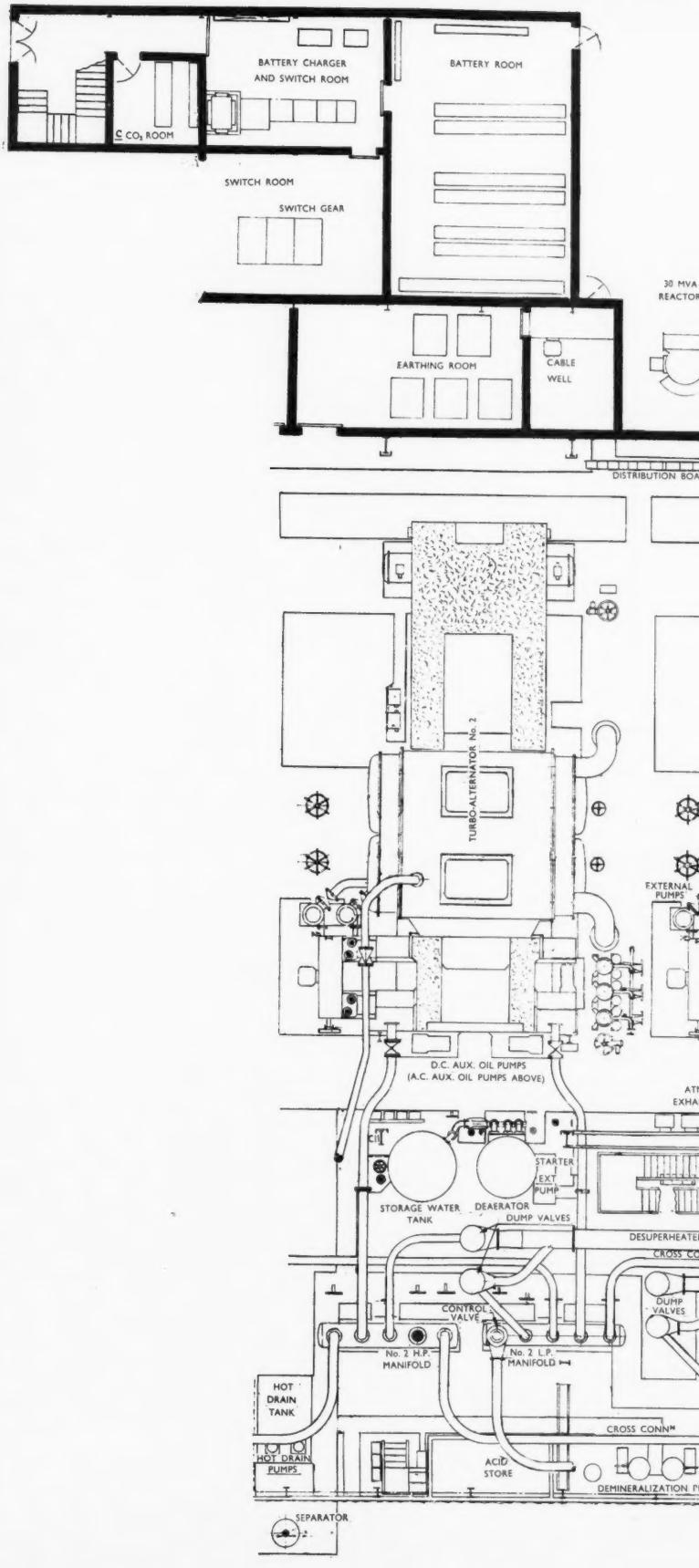
Plan at blower-house floor level of the easterly half of No. 1 reactor building, showing the disposition of the blowers and the main inlet ducts.

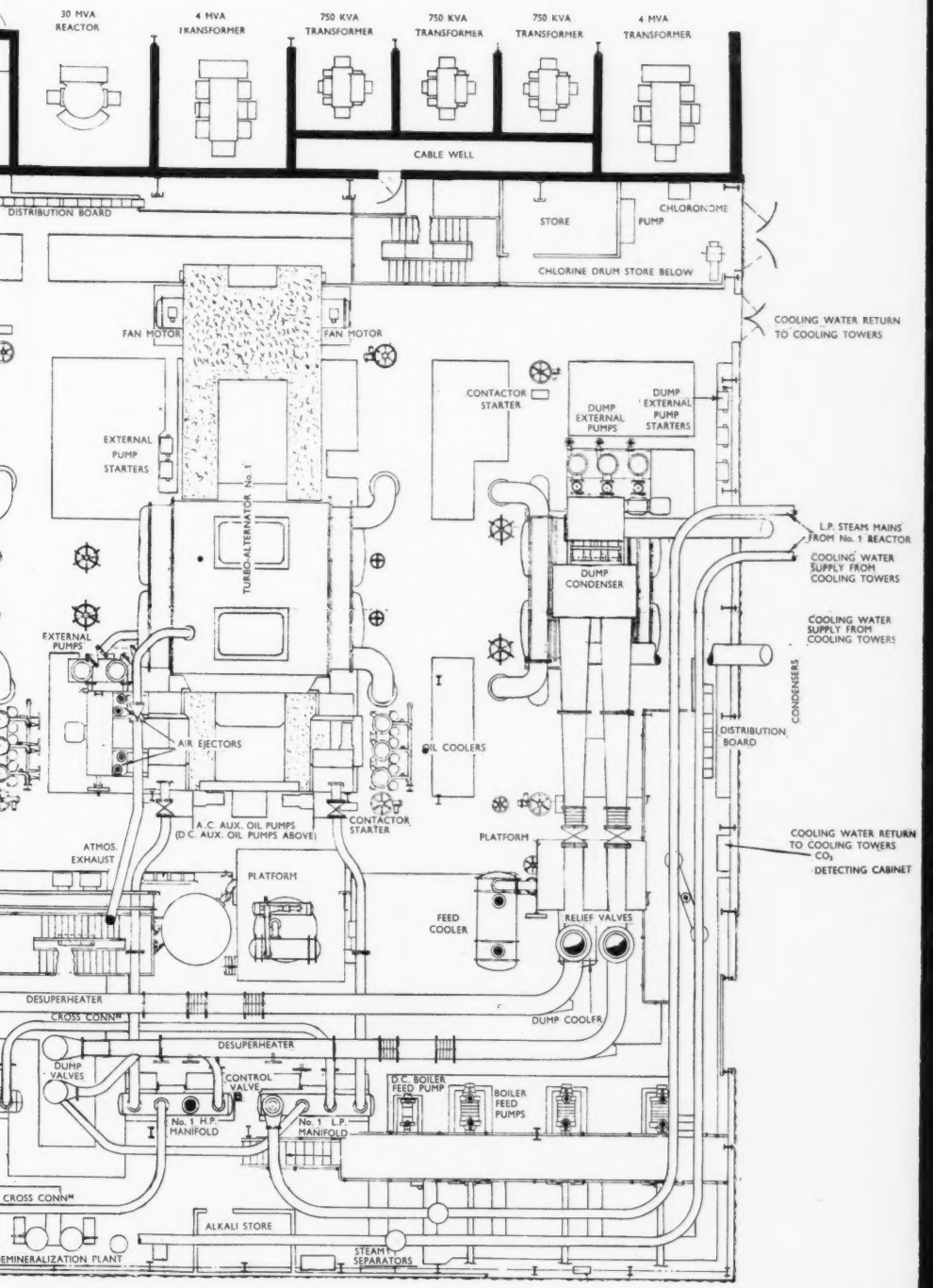
exchangers awaiting erection.
of steam drums and headers
ce after lifting into position.

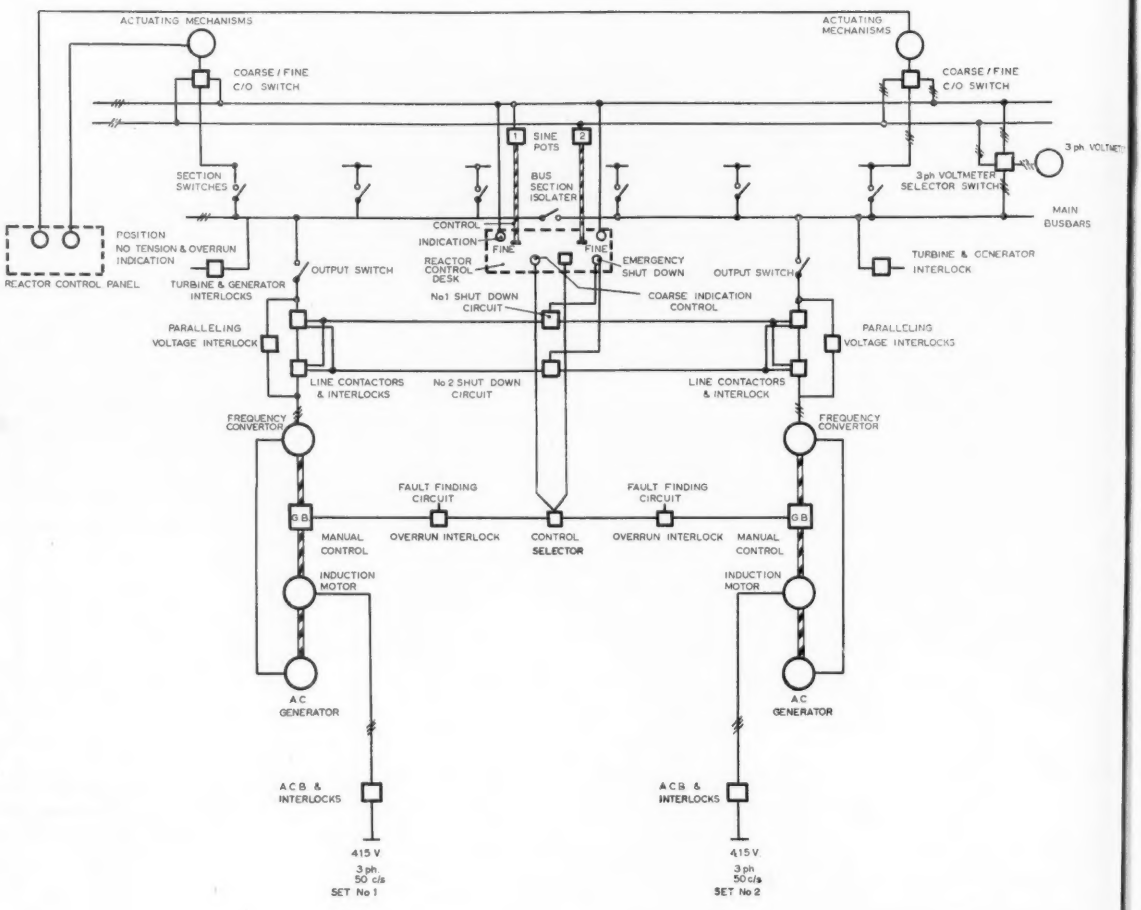




Partial schematic of the gas circuit. The reactor feeds four heat exchangers and is supplied from four liquid CO_2 storage tanks.


BATTERY CHARGER AND SWITCH ROOM
BATTERY ROOM
CO_2 ROOM
SWITCH ROOM
SWITCH GEAR
30 MVA REACTOR
EARTHING ROOM
CABLE WELL
DISTRIBUTION BOA
TURBO-ALTERNATOR No. 2
EXTERNAL PUMPS
D.C. AUX. OIL PUMPS (A.C. AUX. OIL PUMPS ABOVE)
STARTER EXT PUMP
STORAGE WATER TANK
DEAERATOR DUMP VALVES
DESUPERHEATE
CROSS CO
DUMP VALVES
CONTROL VALVE
No. 2 H.P. MANIFOLD
No. 2 L.P. MANIFOLD
HOT DRAIN TANK
CROSS CONN
HOT DRAIN PUMPS
ACID STORE
DEMINERALIZATION
SEPARATOR


30 MVA REACTOR
4 MVA TRANSFORMER
750 KVA TRANSFORMER
750 KVA TRANSFORMER
750 KVA TRANSFORMER
4 MVA TRANSFORMER
CABLE WELL
DISTRIBUTION BOARD
STORE
CHLORONOME PUMP
CHLORINE DRUM STORE BELOW
COOLING WATER RETURN TO COOLING TOWERS
FAN MOTOR
FAN MOTOR
CONTACTOR STARTER
DUMP EXTERNAL PUMPS
DUMP EXTERNAL PUMP STARTERS
EXTERNAL PUMP STARTERS
TURBO-ALTERNATOR No. 1
L.P. STEAM MAINS FROM No. 1 REACTOR
COOLING WATER SUPPLY FROM COOLING TOWERS
DUMP CONDENSER
COOLING WATER SUPPLY FROM COOLING TOWERS
EXTERNAL PUMPS
CONDENSERS
AIR EJECTORS
OIL COOLERS
DISTRIBUTION BOARD
A.C. AUX. OIL PUMPS (D.C. AUX. OIL PUMPS ABOVE)
CONTACTOR STARTER
PLATFORM
COOLING WATER RETURN TO COOLING TOWERS
CO_2 DETECTING CABINET
ATMOS. EXHAUST
PLATFORM
FEED COOLER
RELIEF VALVES
DESUPERHEATER
CROSS CONNᴺ
DUMP COOLER
DESUPERHEATER
DUMP VALVES
CONTROL VALVE
D.C. BOILER FEED PUMP
BOILER FEED PUMPS
No. 1 H.P. MANIFOLD
No. 1 L.P. MANIFOLD
CROSS CONNᴺ
ALKALI STORE
EMINERALIZATION PLANT
STEAM SEPARATORS



(Above) Simplified diagram of the control-rod circuits

COOLING WATER RETURN TO COOLING TOWERS

L.P. STEAM MAINS FROM No. 1 REACTOR

COOLING WATER SUPPLY FROM COOLING TOWERS

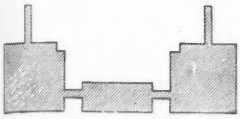
COOLING WATER SUPPLY FROM COOLING TOWERS

CONDENSERS

COOLING WATER RETURN TO COOLING TOWERS

CO_2 DETECTING CABINET

Plan view of the westerly half of the turbine house which is associated with reactor No. 1. No. 2 high-pressure and No. 2 low-pressure manifolds are cross-coupled through valves to similar manifolds in the second reactor system.



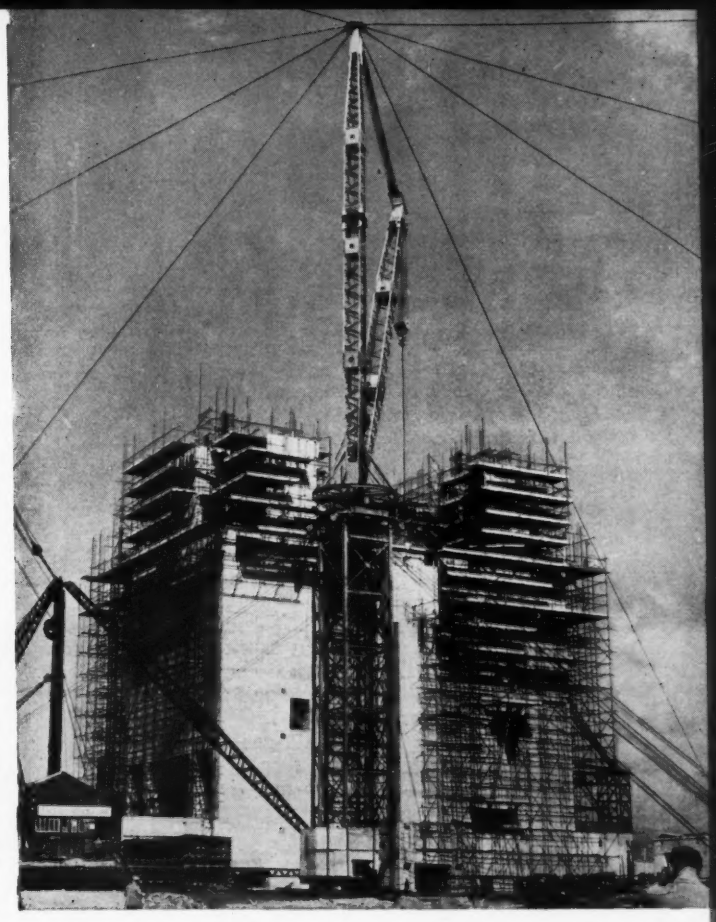
Heavy Lifting Operations

IN any large structural engineering job, the number and capacity of the cranes available play a considerable part in the speed of construction. At Calder Hall it was known in the planning stages that exceptionally heavy lifts would be necessary: moreover, they would also entail considerable delicacy and accuracy in handling.

First, design and development considerations demanded that the heavy pressure vessel be installed after the biological shield had been built and, secondly, the heat exchanger vessels, 80 ft. high and 17½ ft. in diameter, would have to be completed and tested on site before erection on their foundations.

The pressure vessel, as described on page 274, was prefabricated in five sections: bottom dome, two centre sections, diagrid and top dome. The bottom dome weighed 80 tons, centre section 90 tons and diagrid 63 tons. To lift these sections, of about 37-ft. diameter, 120 ft. and then to lower them on to their exact positions required much skill. For these operations a 200-ft.-high, 150-ton capacity derrick was erected alongside the reactor. To prevent distortion during the lift, stiffening rods and ties were fixed to the sections and left in place after erection as additional bracing until the next section had been placed.

The heat exchanger vessels are 17 ft. 6 in. in diameter, 80 ft. high and weigh 178 tons each. These had to be lifted on to a concrete platform 16 ft. high and bolted in an upright position to an accuracy of ⅛ in. A steel collar round the vessel to take the lifting tackle weighed about 15 tons, making the total weight to be lifted from the horizontal position just under 200 tons.



To lift the components of the pressure vessel to a height of 120 ft. and then lower them into position in the biological shield, this 200-ft. high, 150-ton capacity derrick was erected.

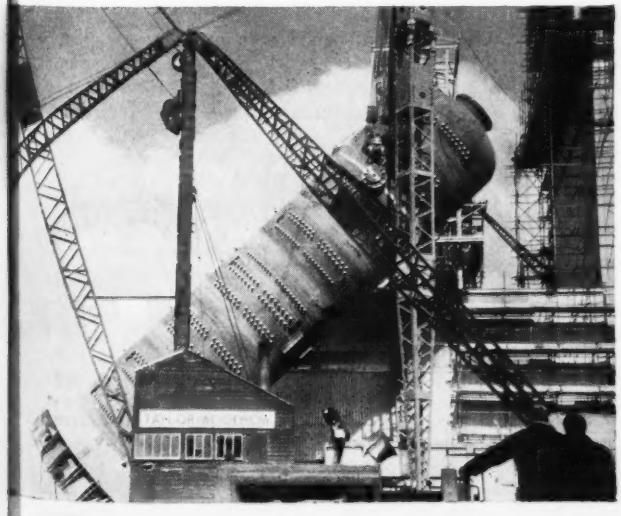
The vessels were fabricated and tested some distance away from the erection site, and had to be transported about a quarter of a mile. The erection of the heat exchangers was entrusted to the constructional division of Costain-John Brown Ltd.

First, the vessel was jacked up about 4 ft. from the cradles on which it had been tested and lowered on to a timber cribbing built to roll the vessel on to a series of dwarf walls, where it was orientated by turning it on greased chocks. The vessel was then loaded on to two four-axle bogies for transport to the site.

The lifting equipment comprised two 102-ft.-high steel gin poles placed each side of the base, with three diesel-engined winches, and an auxiliary crane. The vessel was lined up with the concrete plinth and a standing-way of 12 in. x 12 in. timber laid lengthwise under the vessel. A timber sled was fixed to the base of the vessel and greased to allow it to slide along the standing-way as the vessel moved forward. A 30-ton deadman was set to the rear as a check to the forward movement, the operation being controlled by an 802 Lima crane.

When the vessel was fully suspended, the base, with its 25-ft.-diameter skirt ring, was held clear of the plinth until it was above its seating. The foundation bolts were inserted and the vessel lowered and bolted down. It took eight days from the first jacking-up to arrival at the erection site and a further 22 days to the final dismantling of the lifting poles: the actual lift, however, was accomplished in two hours.

Radio communication between the crane driver and winch operators was used.



Lifting of the heat exchangers was carried out by Costain-John Brown. This view shows the steel collar round the vessel, to which the lifting tackle is attached.

Steam Plant

EACH of Calder Hall's two reactors is associated with two turbo-generator units. Manufactured by C. A. Parsons and Co. Ltd. they are rated at 23 MW, being at present arranged for 21 MW output. Each turbine is a 3,000-r.p.m. unit and consists of a single-flow, 15-stage H.P. cylinder coupled in tandem to a double-flow, low-pressure cylinder. Blading throughout is in stainless iron, and the last two stages of the L.P. rotor are shielded against erosion.

Both H.P. and L.P. units have their own steam chests, each complete with governor valve and emergency stop-valve. Part of the L.P. steam is taken directly from the L.P. boiler unit of the heat exchangers and part is taken from the exhaust of the H.P. unit. The t.s.v. steam conditions are 185 p.s.i. (200 abs.) and 590°F for the H.P. unit and 38 p.s.i. (53 abs.) and 340°F for the L.P. unit.

In addition to the normal H.P. governor valve, there is a pressure-controlled valve, responding to the steam pressure in the H.P. receiver. One of the most important features of the scheme, however, is the valve marked "B" on the simplified diagram. This is a L.P. throttling valve which is operated by a pressure regulator, the L.P. steam pressure being adjusted as required to maintain the temperature of the coolant at the reactor inlet (as explained in the section on Heat Exchangers).

Turbine governors, emergency stop-valves and steam-pressure regulator are oil operated, as are the dump valves, to which further reference is made below. Power oil is obtained from a conventional gear-type pump mounted on a worm-driven cross-shaft which also carries the lubricating oil pump. For providing power oil when plant is not running, there are two motor-driven pumps (one A.C. and one D.C.), operating in parallel, each being of sufficient capacity to provide the full supply.

Each main condenser has a cooling surface of 32,500 sq. ft. The tubes are 1 in. in diameter, and are expanded into the tube plate at one end and secured with Crane packing and ferrules at the other. Under normal meteorological conditions a vacuum of 28¼ in. is secured at the turbine exhaust flange, with a maximum cooling water temperature of 85°F. The flow rate to the condenser at full load is 257,300 lb./hr.

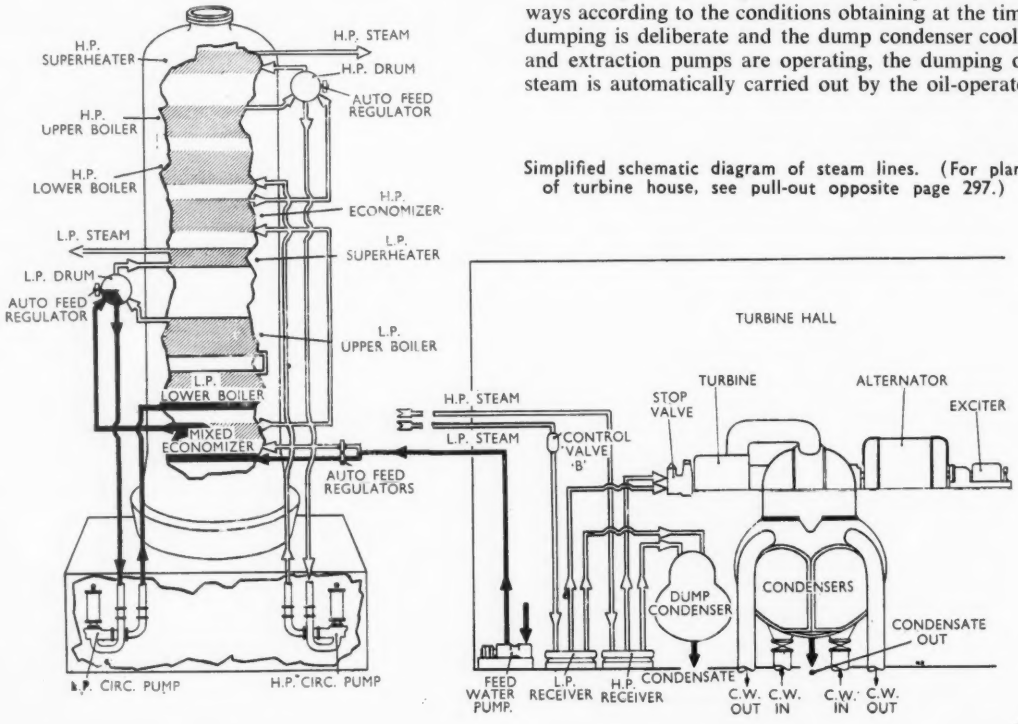
Dump Condenser

Unlike a conventional steam plant, it is not possible to adjust the heat output with the same rapidity as with, say, an oil-fired boiler, so that steam in excess of requirements must be "dumped" as explained below.

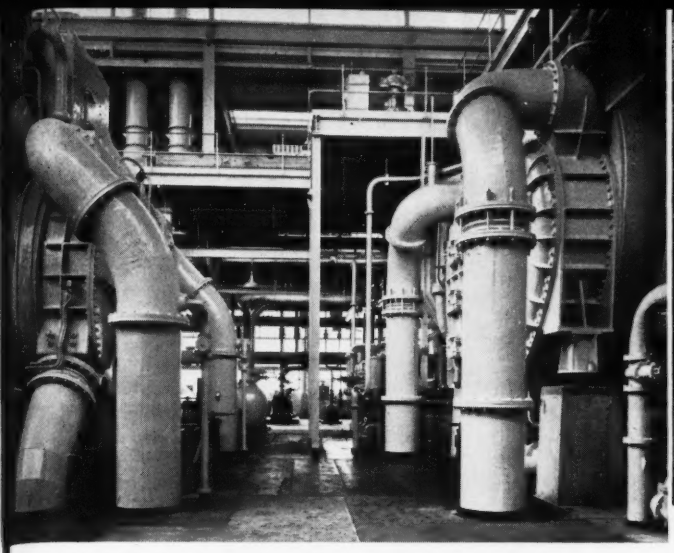
There are two dump condensers, one at each end of the house. Each can deal with the entire full-load steam for two turbines (514,600 lb./hr.).

The disposal of surplus steam takes place in one of two ways according to the conditions obtaining at the time. If the dumping is deliberate and the dump condenser cooling water and extraction pumps are operating, the dumping of surplus steam is automatically carried out by the oil-operated dumping valve under the control of the pressure regulators and turbine governors.

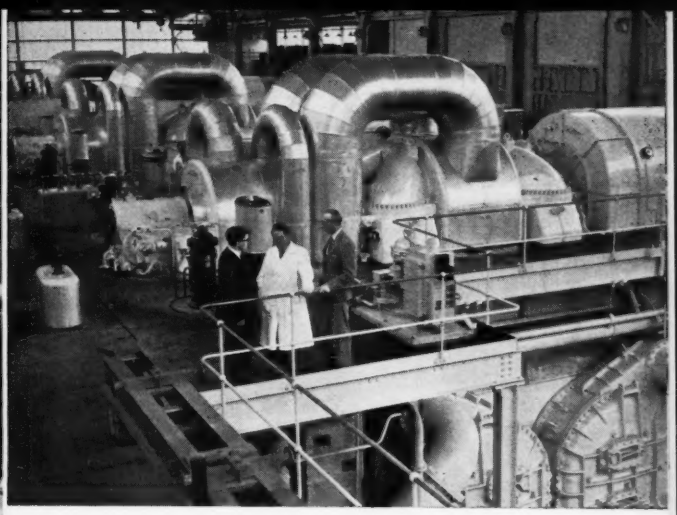
Before the steam can be condensed, of course, it must have its superheat removed. This is carried out by a spray-type desuperheater. The sprays are operated from a control cubicle manufactured by Hopkinsons Ltd., the eight control valves being mechanically operated by a shaft operated from the dumping valve. There are two thermostatically-operated sprays for fine adjustment. This primary desuperheater reduces the steam temperature to approximately 300°F, and



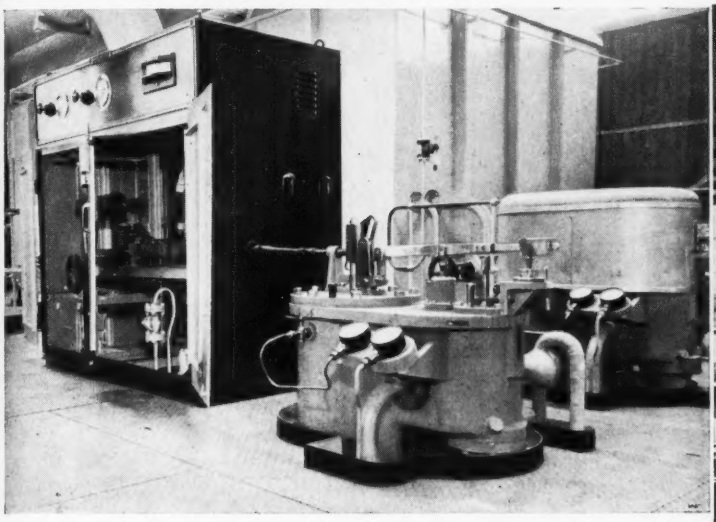
Simplified schematic diagram of steam lines. (For plan of turbine house, see pull-out opposite page 297.)



View in condenser basement showing No. 1 machine condenser on right and dump condenser on left.



General view of the turbine house from the turbine floor.



The Parsons H.P. and L.P. dump valves, showing rotary shaft operating Hopkinson spray-control cubicle for primary desuperheater.

The Hopkinson 20-in. deadweight valves for dumping steam to atmosphere.

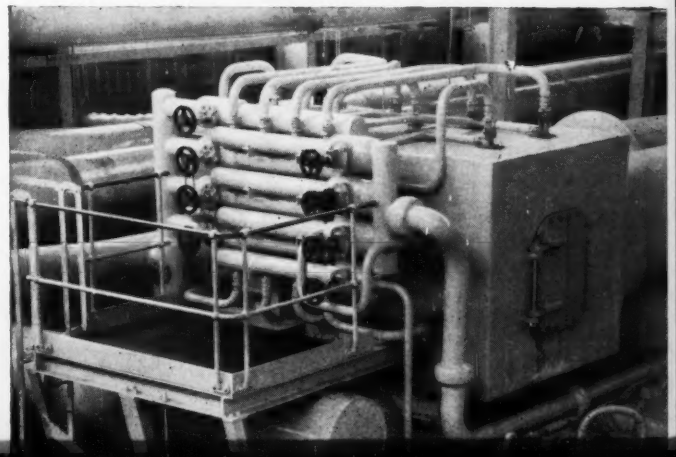
the secondary desuperheating is carried out in the upper portion of the dump condenser, where the temperature is reduced to saturation by further sprays from the extraction-pump discharge.

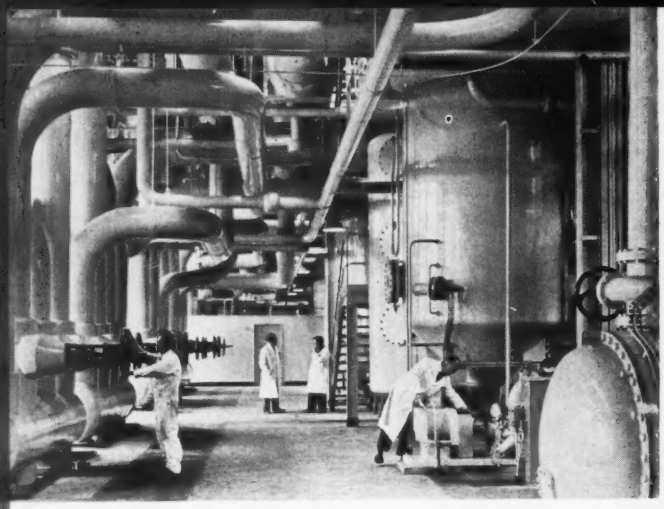
If, however, dumping takes place under emergency conditions, when the dump condenser is at atmospheric pressure and the pumps not running, the condenser is isolated by motor-operated valves interlocked so that they cannot be opened unless the pumps are running, and close automatically if the cooling water fails. In this case, after the steam has passed through the primary desuperheater, it is dumped to atmosphere through a 20-in. relief valve of the deadweight type which can open at 10 p.s.i. The valves were supplied by Hopkinsons Ltd.

Pipe-work

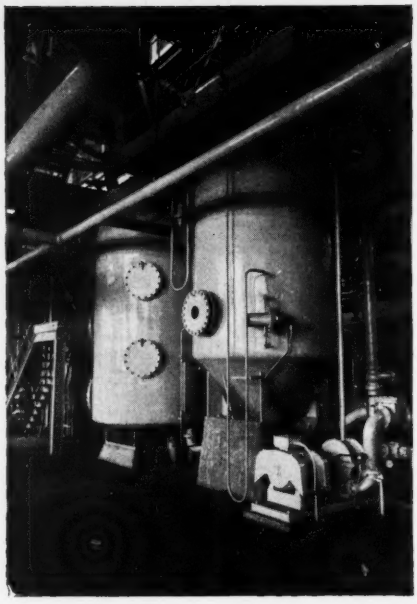
The station pipe-work was supplied and erected by Aiton and Co. Ltd. The steam mains—both H.P. and L.P.—from the heat exchangers to the receivers or manifolds, and from these to the turbine steam chests and to the dump valve inlets, are in 16-in. diameter carbon steel tube with a wall thickness of $\frac{3}{8}$ in. Intermediate joints were butt-welded by metal arc, and examined by γ-radiography. At terminal points the Corwel seal welding technique has been used. Carbon steel and similar techniques are used for the H.P. feed piping from the boiler feed pumps to the heat exchangers. From the dump valve outlet to the dump condenser mild-steel piping is used. Expansion is accommodated by bellows joints fabri-

Parsons secondary desuperheating arrangements on top of dump condenser, showing spray manifolds.



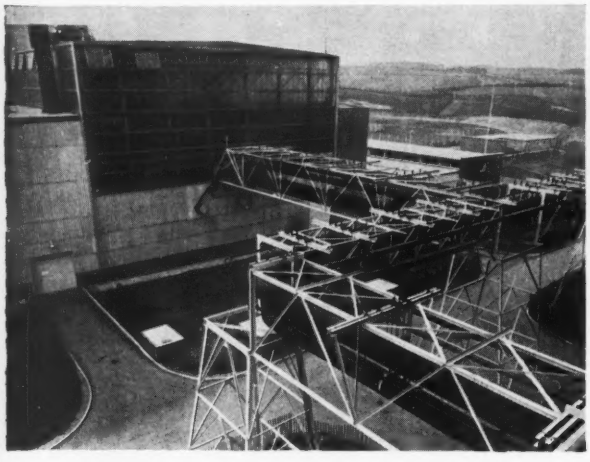


Another view of the condenser basement, showing Nos. 1 and 2 H.P. and L.P. manifolds on left and, on right, de-aerator equipment and feed cooler.

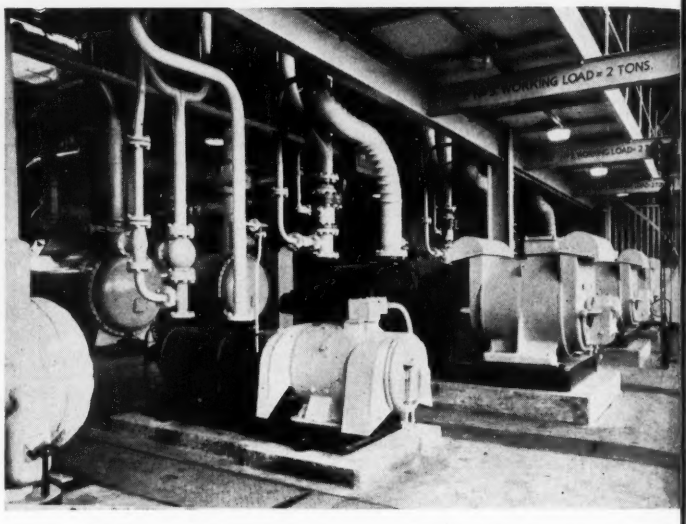


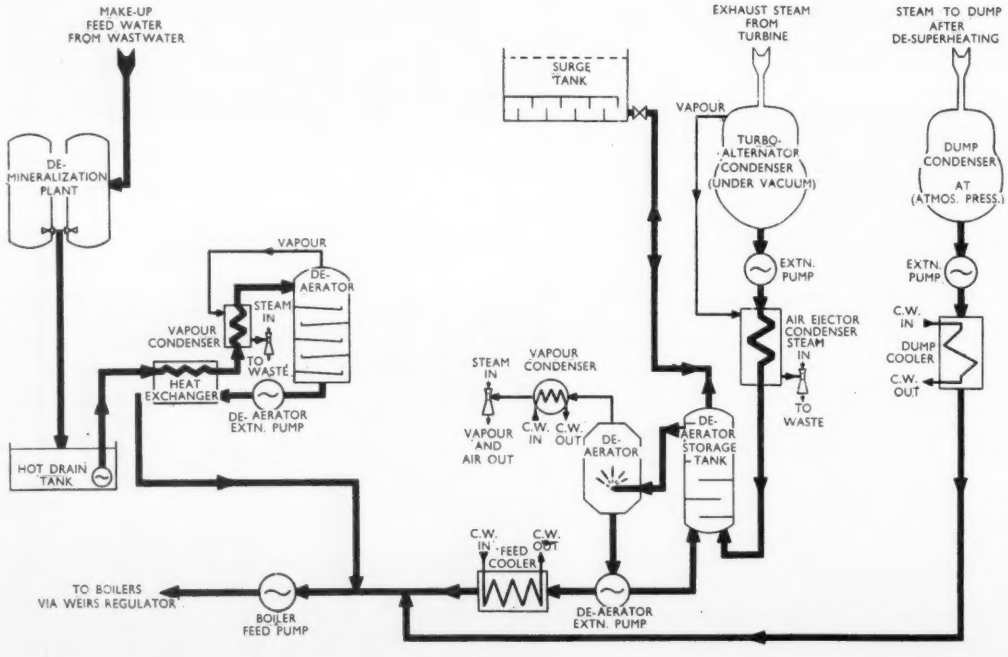
Another view of the Hick Hargreaves de-aerator plant, with storage vessel alongside.

(Below) Boiler feed pumps.



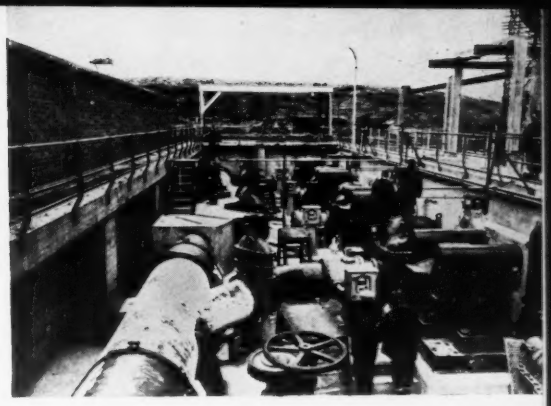
Main steam piping between heat exchangers and turbine house. The twin discharges from the dump system relief valves can be seen in the left-hand corner.





Simplified schematic diagram of feed-water arrangements.

cated from $\frac{1}{16}$ in. stainless steel. The pipe-work includes the L.P. condensate system and piping for station heating and other purposes.



Circulating water pumps near cooling towers.

Feed-water De-aeration

One of the most significant variations from standard power-station conditions is that, so far from attempting to conserve heat in the boiler feed water, it is essential for the maintenance of correct temperature conditions at the reactor that the feed-water temperature shall not be more than about 100°F, i.e., virtually cold feed. In addition, to safeguard the relatively inaccessible tubes of the heat exchangers an exceptionally low oxygen content, i.e., 0.005 cc/litre (5 ppm), has been specified for the feed water. This is accomplished by the use of cold-water "shunt" de-aerators manufactured by Hick Hargreaves Ltd. In these, the feed water is sprayed through nozzles into a vessel maintained at a vacuum corresponding to the water-discharge temperature, the vacuum being maintained by a two-stage ejector unit. Air or other gases liberated in the flashing of the feed water into vapour is ejected to atmosphere, any vapour being condensed in tubular coolers, and returned to the system. De-aerated water is withdrawn from the chamber by an extraction pump and discharged to the feed coolers, a portion being recirculated through the storage vessel of the de-aeration plant, so that water entering the de-aerator has already been subject to partial de-aeration.

Cooling Towers

The towers are slightly larger than normal and the capacity of each tower is 3,000,000 gal./hr. from 87°F to 70°F. They are 290 ft. high with a throat diameter of 104 ft. and a ring beam diameter of 200 ft. Split basins are used, the half-basin capacity being 687,500 gal., and both towers feed into a common suction basin at the pump house, which contains five circulating pumps for the two reactors.

Electrical and Auxiliary Equipment

THE alternators are of Parsons manufacture and are of standard design rated at 23 MW at 11,500 V, 0.8 p.f. Closed-circuit ventilation is used, with two motor-driven fans per unit.

Main Switchgear

For the main 11-kV system Reyrolle metal-clad, horizontal draw-out, switchgear is installed in two switch houses, one at Calder and the other at Windscale substation, some 1,000 yards away. The Calder switchgear comprises two separate three-panel, 500-MVA boards each controlling one generator, one feeder and one 30-MVA grid transformer. At Windscale there is a seven-panel, 750-MVA board divided into two separate three-panel sections, the seventh being a bus section switch. Each of the three-panel sections controls a generator, grid transformer and feeder as before, so that two generators are switched at Calder and two at Windscale. Remote control is provided at Calder for the Windscale switching, while Windscale has local control in addition.

The control switchgear at Calder is of the corridor type, with instruments, controls and mimic diagram on the front panel and relay cubicles at the rear. Controls for all four generators and the tap-changing gear for the grid transformers are centralized on a desk-type control board.

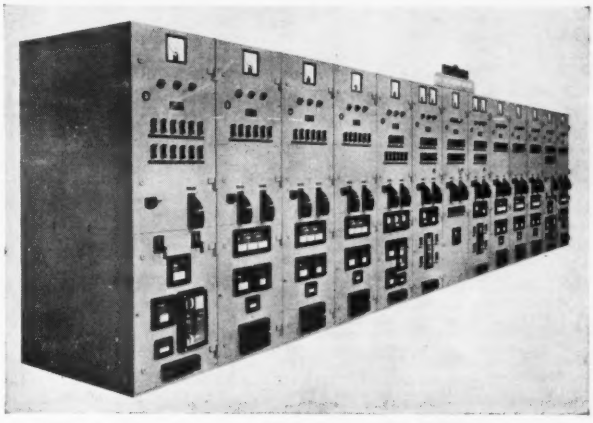
There is a similar corridor-type control board at Windscale which is, however, normally unmanned, control being from Calder.

All the 11-kV gear has bus zone protection of the high-impedance differential type, giving both phase and earth fault protection.

The neutral earthing equipment is also of Reyrolle manufacture. They were responsible as well for battery and control cable installation.

Auxiliary Switchgear

Auxiliary equipment at Calder is operated at two voltage levels, 415 and 3,300 V, and the auxiliary switchgear is English Electric air-break type OB3 and OB33L respectively. For the turbine auxiliaries there are two 3,300-V boards of 14 and 15 panels and two eight-panel, 415-V boards. There is also a 13-panel, 3,300-V board for the circulating water pumps in the pump house. Each reactor has a 13-panel, 415-V board which feeds, amongst other items, the generator sets for control-rod operation.



English Electric 13-panel auxiliary board of OB3 gear for 415-V service.

Cables

Cables were the responsibility of British Insulated Callender's Cables Ltd. and the B.I.C.C. group has supplied and installed 17½ miles of 11-kV cable, seven miles of multicore control cable, and four miles of telephone cable, with more than 100 terminal boxes and marshalling kiosk. The connections between Calder switchgear and two of the generators is by single-core cables in trefoil formation and from the other two alternators to the Windscale switchgear by

An illustration of the Reyrolle control board is shown on p. 280.

18 single-core cables laid in six trefoil groups. This main cable route is 1,100 yards long, and is shared by 18 multicore control cables. For the majority of their length they are buried in a trench 15 ft. wide and 3 ft. 6 in. deep. The crossing of the Calder River is by a steel bridge 250 ft. long. The construction work was carried out by B.I.-Callender's Construction Co. Ltd.

One of the most interesting contributions from a technical standpoint was the development of two new types of cable for the fuel charge and discharge machines of the reactors. These are capable of withstanding the high temperature and radiation encountered by the grabs used to handle the reactor fuel rods without failure or loss of electrical performance. The first type, of which over 40 lengths are being supplied, contains six 19.0076 nickel-plated-copper P.T.F.E. insulated cores laid around a central 110-ton-quality steel strand and is used for the electrical control of the reactor charging and discharging grabs. The second type, which is being installed experimentally at Calder, incorporates a flexible central duct in addition to the electric wires, and enables electro-pneumatic control to be achieved with the use of only one flexible cable.

Lighting, heating and small power services throughout, including a considerable amount of instrumentation and

PROVISIONAL LIST OF CONTRACTORS

ACCLES AND POLLOCK LTD., Oldbury, Birmingham
Stainless-steel tubing including tubes of .003 in. wall thickness.

ACCURATE RECORDING INSTRUMENT CO. LTD., Aric Works, Garth Road, Morden Surrey
Instruments.

AITON AND CO. LTD., Stores Road, Derby
H.P. and L.P. steam mains. Also L.P. condensate piping, etc.

APPLEBY AND IRELAND LTD., Basingstoke
Vacuum and pressure measuring devices.

BABCOCK AND WILCOX LTD., Farringdon Street, London, E.C.4.
Main contractors for the eight heat exchangers.

N. G. BAILEY AND CO. LTD., Kirkstall Road, Leeds 4.
Electrical installation for the whole of the station lighting and small power.

J. BLAKEBOROUGH AND SONS LTD., Brighouse, Yorks.
Valves on CO_2 gas circuit, 4 ft. 6 in. dia.

BRITISH ACHESON ELECTRODES LTD., Grange Mill Lane, Wincobank, Sheffield
Graphite blocks for both reactors.

BRITISH THOMSON-HOUSTON CO. LTD., Rugby
Two pumpless rectifier units.

BRITISH INSULATED CALLENDER'S CABLES LTD., 21 Bloomsbury Street, London, W.C.1
11-kV cables, multicore cables, and special fuel-element handling cables.

J. BROCKHOUSE AND CO. LTD., Victoria Works, West Bromwich, Staffs.
Roller bogies for heat exchangers.

BROOKHIRST SWITCHGEAR LTD., Northgate Works, Newry Park, Chester
Electrical equipment for discharge magazine dryer.

BURNETT AND LEWIS LTD., 148 High Street, Erdington, Birmingham 24
Humidryers in CO_2 gas circuit.

CABLE JOINTERS LTD., 49 Avenue Road, London, W.3
Cable jointing.

CARBON DIOXIDE CO., Devonshire House, Piccadilly, London, W.1
CO_2 gas, storage plant and evaporators.

CHATWOOD-MILNER LTD., Shrewsbury
"Coffins" for discharged fuel elements and element grabs.

CHESTERFIELD TUBE CO. LTD., Chesterfield, Derbyshire
Forged steel headers for heat exchangers.

CHLORIDE BATTERIES LTD., Swinton, Manchester
Two sets 120 OFW.13 Chloride Plante battery cells; each 1,950 Ah at 10 hour rate.

E. K. COLE LTD., Southend-on-Sea
Ionization chambers and amplifiers.

COLVILLES LTD., 195 West George Street, Glasgow
"Coltuf" steel for heat-exchanger shells.

CONSETT IRON AND STEEL CO. LTD., Consett, Co. Durham
Lowtem steel for reactor pressure vessels.

COSTAIN-JOHN BROWN LTD., 73 South Audley Street, London, W.1
Heavy lifting gear for site work.

CROSSLEY BROS. LTD., Openshaw, Manchester 11
Four auxiliary diesel generators.

DARLINGTON INSULATION CO. LTD., 38 Great North Road, Newcastle upon Tyne 2
Insulation for reactor pressure vessel, heat exchangers and ducting.

DELAPENA AND SON LTD., Zona Works, Russell Place, Cheltenham, Glos.
Induction heating equipment for brazing stainless-steel tubes of burst-slug detection gear.

DEWRANCE AND CO. LTD., Great Dover Street, London, S.E.1
Heat-exchanger mountings and parallel-slide valves for steam and feed lines.

EDWIN DANKS AND CO. (OLDBURY) LTD., Oldbury, near Birmingham
"Dirt lock" houses for heat-exchanger erection, galleries and ladders.

ELECTRIC FURNACE CO. LTD., Queens Road, Weybridge, Surrey
Induction heating equipment for stress-relieving heat exchangers.

ELLIOTT BROS. (LONDON) LTD., Century Works, London, S.E.13
Recorders associated with burst-slug detection.

ENGLISH ELECTRIC CO. LTD., Marconi House, Strand, W.C.2
415-V and 3,300-V auxiliary switchgear.

ENGLISH STEEL CORPORATION LTD., River Don Works, Sheffield 9
6-in. M.S. plates forming thermal barrier for each reactor.

FAIREY AVIATION CO. LTD., North Hyde Road, Hayes, Middx.
Machining of fuel-element cans.

ALEXANDER FINDLAY AND CO. LTD., Motherwell, Scotland
Structural steelwork.

FLUIDRIVE ENGINEERING CO. LTD., Isleworth, Middx.
Sinclair coupling in CO_2 blower motor drive.

HICK, HARGREAVES LTD., Bolton
De-aerators for feed water.

MATTHEW HALL AND CO. LTD., 26-28 Dorset Square, London, N.W.1
Services in connection with construction of reactor and burst-slug detection plant.

HAYWARDS STEEL DOORS LTD.
Steel doors for turbine hall and station generally.

HAYWARD TYLER LTD., Luton, Beds.
Glandless pumps for heat exchangers.

HONEYWELL BROWN LTD., 1 Wadsworth Road, Perivale, Greenford, Middx.
Recorders.

HOPKINSONS LTD., Britannia Works, Huddersfield
Parallel-slide valves, including some electrically operated; various exhaust, relief, isolating and non-return valves, steam traps, centrifugal oil purifiers. De-superheater control cubicle; atmospheric dumping valves.

JAMES HOWDEN AND CO. LTD., 195 Scotland Street, Glasgow, C.5
Eight 33,300 cu. ft. min. air blowers, 13.3 w.g., for cooling pressure vessel surface, thermal shield, etc.

ISOTOPE DEVELOPMENTS LTD., Aldermaston Wharf, near Reading, Berks.
Reactor gamma monitor.

R. JENKINS AND CO. LTD., Rotherham
300 tons of M.S. ductwork, 4 ft. 6 in. bore, $\frac{1}{4}$ in. thick, 1,500 ft. run. Handles CO_2 cooling gases.

G. KENT LTD., Luton, Beds.
Kent Multelec recorders and complete control panels.

THE WALTER KIDDE CO. LTD., Lux Works, Bellvue Road, Northolt, Middx.
Fire extinguishers.

LANCASHIRE DYNAMO AND CRYPTO LTD., Trafford Park, Manchester
Circulating pumps and motors.

LLOYDS REGISTER OF SHIPPING, Leadenhall Street, London, E.C.3
Land Division responsible for survey and inspection of pressure plant. Special tests devised for reactor vessels and heat exchangers.

MARSTON-EXCELSIOR LTD., Fordhouses, Wolverhampton
Special brazing and cooling arrangements for burst-slug detection gear.

MATHER AND PLATT LTD., Park Works, Manchester 10
Main blower motors and associated Ward-Leonard motor generators. H.P. and L.P. circulating pumps.

MEASUREMENT LTD., 119 Union Street, Oldham, Lancs.
Flow indicators.

METROPOLITAN-VICKERS ELECTRICAL CO. LTD., Trafford Park, Manchester 17
Control rod actuating mechanisms (electrically driven).

NEGRETTI AND ZAMBRA LTD., 122 Regent Street, London, W.1
Hygrometers.

NEW WESTER (ENGINEERING) LTD., 136 Meadow Lane, Leeds 11
Meters.

PAROLLE ELECTRICAL PLANT CO. LTD., Princes Buildings, Newcastle upon Tyne 1
Switchboards associated with distribution equipment.

C. A. PARSONS AND CO. LTD., Newcastle upon Tyne
Main contractors for four 23-MW turbo-alternators, dump condensers, CO_2 coolant blowers and associated gas circuit.

PLESSEY NUCLEONICS LTD., Vicarage Lane, Ilford, Essex
Burst-slug detection equipment.

POLLARD BEARINGS LTD., Ferrybridge, Knottingley, Yorks.
Graphite support bearings.

PULSOMETER ENGINEERING CO. LTD., Oxford Road, Reading
Pumps.

RECORD ELECTRICAL LTD., Manchester
Instruments.

A. REYROLLE AND CO. LTD.
11-kV generator switchgear with associated control and ancillary equipment.

J. RIGBY AND SONS LTD., Salford
Oval rolled section for heat-exchanger studs.

ROYCE ELECTRIC FURNACES LTD., Sir Richard's Bridge, Walton-on-Thames, Surrey
Discharge machine magazine air dryers.

SILICA-GEL LTD., 62 Shaftesbury Avenue, London, W.1
Dryers used in erection of heat exchangers.

STEEL CO. OF WALES LTD., Abbey Works, Port Talbot, Glam.
General constructional steel.

STEEL CO. OF SCOTLAND LTD., 132 Blochairn Road, Glasgow, N.
Thermal sleeves for heat exchangers.

STEWARTS AND LLOYDS LTD., Winchester House, Old Broad Street, London, E.C.2
Electric resistance-welded tube for heat exchangers.

STRACHAN AND HENSHAW LTD., Steelhoist Works, Bristol 2
Charge and discharge gear for reactors.

STURTEVANT ENGINEERING LTD., Southern House, Cannon Street, E.C.4
Dust-extraction plant.

ST. GEORGE (ENGINEERS) LTD., Ordsall Lane, Trafford Bridge, Manchester
Shot-blast plant for heat exchangers.

TALBOT-STEAD TUBE CO. LTD., Green Lane, Walsall
Stainless steel tubes.

TANGYES LTD., Cornwall Works, Smethwick, Birmingham
Hydraulic ram for lifting lid of burst-slug coffin.

TAYLOR, WOODROW CONSTRUCTION LTD., Ruislip Road, Southall, Middx.
Main contractors for all building and civil engineering work at both Calder "A" and "B".

TILGHMANS LTD., Broadheath, Manchester
Auxiliary shot-blast equipment.

G. AND J. WEIR LTD., Glasgow, S.4
Feed water regulators.

VOKES LTD., Guildford
Genspring pipe supports.

WHARTON CRANE AND HOIST CO. LTD., Station Road, Reddish, Stockport
Overhead cranes.

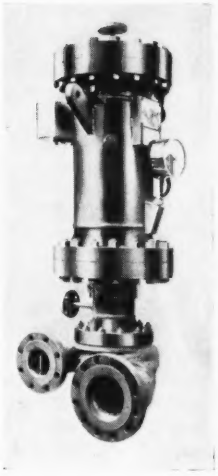
WHESSOE LTD., 25 Victoria Street, London, S.W.1
Pressure shells for the two reactors in 2-in. thick mild steel.

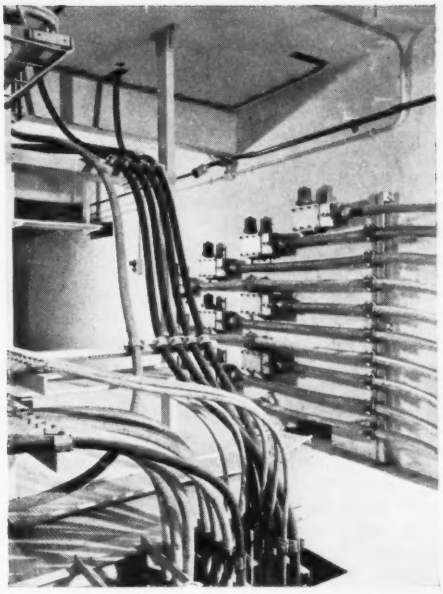
WHIPP AND BOURNE LTD., Switchgear Works, Castleton, Rochdale, Lancs.
Two sets of BTH rectifiers for feeding reactor auxiliary equipment.

(Left) Hayward - Tyler glandless pump for the heat-exchanger circulation.

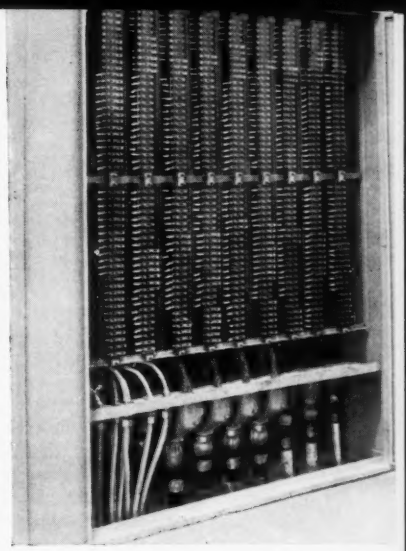
(Centre) 11-kV cables on cable mezzanine floor. On the rear wall are 1.0 sq. in. cables entering sealing bells of No. 3 generator pit. Multicore cables are on the left.

(Right) 900-way marshalling kiosk for multicore cable distribution.

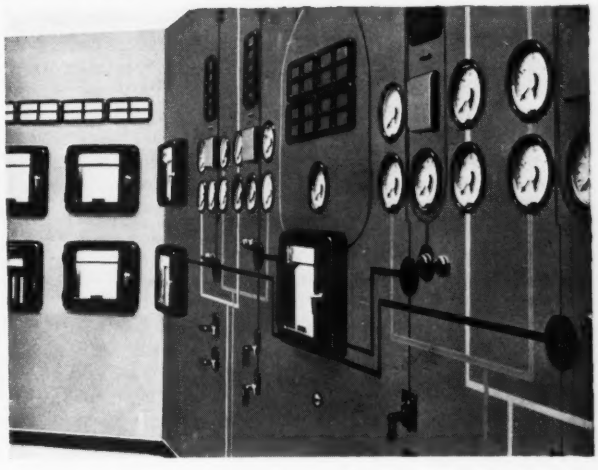




(Below) Laying the main cables from Calder to Windscale (B.I.C.C.).



(Below) Part of the reactor control panel in the main control room, showing some of the instruments supplied by George Kent Ltd.



thermocouple work, was carried out by N. G. Bailey and Co. Ltd. During the early phases of construction they were responsible for a temporary service network covering the whole site, with feeder pillars and distribution arrangements, as well as temporary floodlighting and a comprehensive street-lighting system.

Rectifiers

For operating the cooling fans, lighting instrumentation, etc., of each reactor there is a D.C. supply from a separate rectifier set. Manufactured by the British Thomson-Houston Co. Ltd. to the order of Whipp and Bourne Ltd, each set consists of two six-phase pumpless steel-tank mercury rectifiers with an output of 233/400/566 kW at 200/246/335 V. These rectifiers are operated from the 415-V three-phase supply through a rectifier transformer with 33-position on-load tap changing.

Batteries

Chloride Batteries Ltd. supplied two large units for emergency service to allow operation of reactor auxiliaries, such as pumps, fans, instrumentation and emergency lighting, normally energized from the rectifier units. Each battery consists of 120 Plante cells in lead-lined wood boxes of 1,950 Ah capacity at the 10-h rate, and can supply 1,200 amp. for 30 minutes. They usually float in parallel with their associated rectifiers to provide a trickle charge under normal conditions or a quick re-charge of a battery after a heavy discharge.

Reactor Cooling Fans

James Howden and Co. Ltd. supplied the induced-draught cooling fans (a total of eight) for the cooling of the reactor vessels. Each fan has a capacity of 33,300 cu. ft./min. against 13.3-in. w.g. and is driven by a 120-h.p. motor.

AUXILIARY EQUIPMENT

Isotope Developments Ltd. provided monitoring equipment for the vicinity of the reactor, this being their type 1457A reactor gamma monitor. Consisting of two main units, the head amplifier with ionization chamber and a D.C. amplifier with high-level alarm, the instrument has a logarithmic scale and has a range of $0.01\text{-}10^3$ R/hr., the alarm system being adjustable over the whole range.

George Kent Ltd. provided a large number of "Multelec" recorders for the measurement and control of radioactivity, power level, pH, conductivity, B.T.U., temperature flow, draught gauges, etc.

Royce Electric Furnaces Ltd. provided low-temperature, forced-air flow cabinets for drying baskets associated with the fuel units which have been immersed in water. Dimensions of the baskets are 3 ft. 3 in. diameter by 4 ft. 6 in. high and each is heated to 350°F for 15 minutes on a semi-continuous basis.

Future Nuclear Power Programme in Britain

The programme for electricity generation from atomic energy will take a fundamental step forward in the new year when the first contracts for the construction of nuclear power stations will be placed by the C.E.A.

by
R. N. MILLAR, M.A., B.Com., A.M.I.Mech.E.
Manager, G.E.C.-Simon Carves Atomic Energy Group

THE designs have now been completed for the reactors which are to form the first stage of the British atomic power programme. These designs have been carried out in close consultation with the U.K.A.E.A. by the four groups of large engineering companies formed for this purpose about two years ago.

These Stage 1 reactors are, as might be expected, basically similar to the Calder Hall type; i.e. they are graphite moderated, carbon dioxide cooled and are fuelled with natural uranium. They differ chiefly from Calder Hall in three ways: first, the size of the reactor core has been considerably increased; secondly, the thermal efficiency of the plant has been improved; thirdly, provision has been made for charging and discharging the reactor under load.

The increased core size has been made possible by the entirely successful construction of the pressure vessels used for the Calder Hall reactors. These pressure vessels were fabricated on site from 2-in. thick mild-steel plate, and the experience gained has made it practicable to use 3-in. thick plate for the Stage 1 reactors. It has thus been possible to build a larger pressure vessel, to increase the size of the reactor core and to raise the coolant gas pressure.

As a consequence of this increased core size, the leakage of neutrons from the core has been reduced and the effective reactivity increased. This increase has been used in radial flattening of the neutron flux by inserting absorbing material in the central region of the pile; in this way the ratio of the average flux to the maximum flux has been increased.

The fuel elements are very similar to those used in the Calder Hall reactors, i.e. they are solid cylindrical rods of natural uranium metal contained in finned cans of magnesium alloy. By virtue of the increase in gas pressure and temperature, an increase in the maximum channel heat rating has been obtained. The gas outlet temperature is considerably greater than that used in Calder Hall. This is largely because the Calder Hall reactors are intended primarily for plutonium production, and thermal efficiency is of secondary importance, but it is also the result of additional metallurgical and heat transfer research work which has been undertaken since Calder Hall was designed. Steam pressures and temperature have also been increased, and the thermal efficiency has been raised to about 28%.

The net effect of the increased size of the reactor and the higher thermal efficiency has been to raise the electrical output to between two and three times that of Calder Hall.

The provision of equipment for charging and discharging the reactor under load is most important in reducing the costs of power production. Ideally, as the rate at which uranium is burnt up varies throughout the reactor core, charge and discharge should be a continuous operation; if the reactor is to be discharged in large blocks at infrequent intervals, incompletely burnt fuel must be discharged with spent fuel, and the average degree of burn-up of the fuel reduced. It is also desirable, in order to obtain the highest possible burn-up, to be able to remove partly burnt fuel from the core and replace it in another position. The time required to charge and discharge the complete reactor is a significant fraction of the life of the charge when the reactor is running on full load (bearing in mind that the reactor has roughly 3,000 fuel channels). Finally, it is clearly most desirable to be able to remove and replace a fuel element which has failed before reaching the end of its useful working life without having to shut down the reactor.

The remainder of the plant, i.e., heat exchangers, turbines, etc., is broadly similar to Calder Hall in design, but of increased capacity. However, the capital cost of the plant per unit of electricity will be significantly less than for Calder Hall, and provided it is possible to obtain the estimated fuel life of about 2,500 MWD/T, the Stage 1 stations should produce electricity at about the same price as modern coal-fired stations.

There is little doubt that the graphite-moderated, gas-cooled reactor, using natural or possibly slightly enriched uranium, will have lower running costs than any other type of reactor which could be built in this country at the present time. Although it is very large in relation to its heat output, the engineering problems met with in its construction are for the most part orthodox and, since exotic or expensive materials are not required, its capital cost is reasonably low. Parasitic losses of neutrons occur only in the moderator and in the magnesium cans and are therefore low, and due to its large size the leakage of neutrons from the core is also low; hence the neutron economy of the reactor is good and the conversion factor is relatively high.

The size and capital cost of a solid-fuelled heterogeneous power reactor depends to a considerable extent on the weight of fuel it contains. Consequently, reducing the capital cost per kilowatt of capacity usually involves increasing the heat rating per tonne of fuel. Any appreciable increase in thermal efficiency involves fuel elements operating at higher temperatures. No significant advance in either of these directions beyond what has been achieved in the Stage 1 designs is likely without changes in fuel-element shapes (e.g. flat plates), in canning material (e.g., beryllium or stainless steel), coolant (e.g., hydrogen, water or liquid metal) or fuel (e.g., uranium carbide or oxide). Furthermore, a higher fuel rating entails a higher level of fission product poisoning. All these changes result in poorer neutron economy.

The fuel will thus require enrichment to make the reactor work and, due to the poorer neutron economy, the conversion factor will tend to be inferior to that of a natural uranium reactor. If the excess reactivity at operating power with which the reactor starts life is the same as that of a natural uranium reactor, it will fall more rapidly in the case of the enriched reactor, so that each tonne of fuel must be rejected when it has provided a smaller number of megawatt days of heat.

It is true that extra reactivity could be built into the feed fuel to lengthen the burn-up, but this may be less economic in an appreciably enriched reactor than in a near-natural uranium reactor, because the proportion of natural uranium to enrichment burnt can never be very high in the former type. It is also likely to be more difficult to make the necessary rearrangements of fuel to achieve a greater burn-up in the enriched reactor, since it is compact and has a relatively small number of fuel elements.

The enriched reactor with a relatively poor conversion factor can therefore have a capital cost per kilowatt below that of a natural uranium reactor, but only at the expense of a probable increase in the fuel cost per kilowatt hour. The point at which it becomes economic depends on the comparative cost of enriched and natural uranium, on the

reduction in capital cost achieved by using enrichment, on the rate of annual capital charges, and on the load factor at which the power station operates.

The probability is that in this country, at present prices, uranium considerably enriched by the gaseous diffusion process as a continuous feed for a power reactor with a relatively poor neutron economy will not produce cheaper power than the Stage 1 design. However, this should not discourage the early development of enriched types of reactor.

In the first place, the relative costs of natural uranium and of enriched uranium are likely to alter in favour of enrichment at some time in the future.

Secondly, whilst the U.K.A.E.A. has undoubtedly made a wise choice in selecting the gas-cooled, graphite-moderated natural uranium reactor for the first stage of the nuclear power programme in this country, the situation elsewhere may be different. In the U.S.A., for example, annual capital charges on a power station generally amount to 14% or 15% of the capital cost, compared with 8% or 9% in this country. On the other hand, as the result of cheaper thermal power, enrichment by gaseous diffusion in the U.S.A. is cheaper than in the U.K. Thus the relationship between capital and running cost per kilowatt hour is quite different in the two countries, favouring enrichment combined with reduced capital costs much more in the United States than here. The same may be true of countries where capital is scarce and capital charges and rates of profit high.

Thirdly, there may soon be a market abroad for small nuclear stations operating on enriched fuel. While this type of reactor would generally be uneconomical in highly industrialized countries where large central power stations are required, it might be competitive with small, conventional power stations in regions where conventional fuel prices are high. If a future export market develops along these lines, there is clearly a need for the British nuclear power industry to gain experience on various types of reactor employing enriched fuel at the earliest opportunity. As in the U.S. Nuclear Power Demonstration Programme, it may be desirable to design and build prototype power stations that are not necessarily economic here in order to be ready to exploit the best types for overseas markets as soon as the demand arises.

So far, we have been considering reactors fuelled only with uranium, but the development of future reactors will be bound up with the gradual replacement of uranium-235 as fissile material by plutonium and uranium-233. The fast reactor operating on the plutonium/uranium-238 fuel cycle should produce more fissile material than it consumes, and thermal reactors with the thorium/uranium-233 cycle may achieve approximate self-sufficiency in fissile material. Surplus fissile material should therefore be available for burning in reactors which consume more fissile material than they produce.

In reactors using manufactured fissile material, high fuel ratings will be desirable owing to the high cost per tonne of the fuel stock in the reactor. This is particularly true of the fast reactor where the proportion of fissile material is very high, necessitating liquid-metal cooling to achieve an economic heat rating. With the thorium/uranium-233 thermal reactor a high enough fuel rating might possibly be achieved with gas cooling, but it seems more likely that water or liquid-metal cooling would be necessary. Ultimately, the most desirable type of reactor may prove to be one using some form of liquid fuel, in order to achieve low fuel processing costs, high fuel rating and very good neutron economy. However, the difficult material problems encountered in these reactors will probably require a long period of development.

The production and feeding back into a reactor of fissile material such as plutonium or uranium-233 is usually referred to as "recycling", by which it is meant that the reactor produces some or all of the fissile material it needs. Since depleted fuel containing fissile material will generally be sold to a processing plant, and many reactors will be either net buyers or net sellers of fissile material, the market value of this material will determine which reactors are economic. A change in this value may make some previously economic reactors uneconomic and vice versa. For example, the fast breeder reactor, by eventually depressing the price of plutonium, might make the building of new natural uranium reactors uneconomic, since they rely on plutonium sales for part of their revenue.

It is clear that the future value of plutonium will depend to a great extent on the success or failure of the fast reactor and on the physical and metallurgical difficulties encountered in using plutonium in thermal reactors. If this reactor is a complete success economically, its successors may absorb all civil supplies of plutonium for many years. The picture of the future is not likely to become at all clear until this particular use of plutonium has been demonstrated.

Le Programme Futur Pour L'Énergie Nucléaire en Grande Bretagne

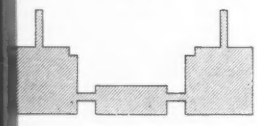
Les dessins des réacteurs qui sont destinés à former le premier stade du programme britannique de l'énergie nucléaire sont maintenant terminés. Ces dessins, qui ont été soumis par quatre groupes de grandes sociétés de construction mécanique, seront basés sur le réacteur de Calder Hall mais comprendront un nombre d'améliorations importantes. L'épaisseur du bac de pression a été portée à 76,2 mm pour permettre une plus forte grandeur de noyau entraînant en conséquence une meilleure économie des neutrons et un meilleur aplatissement de l'effluent. Le rendement thermique de l'installation a été augmenté avec de plus grandes pressions de réfrigérant et de plus hautes températures de fonctionnement à environ 28%, et les appareillages de chargement et de déchargement ont été conçus pour le fonctionnement lors de la marche à pleine puissance du réacteur. Cela permettra une plus grande donnée de consommation que les calculs actuels situent à 2.500 MWD/T.

Programm der zukünftigen Atom-Kraftwerke in Gross-Britannien

Die Entwürfe der Reaktoren, die das erste Stadium im Programm der britischen Atom-Kraftwerke darstellen, sind jetzt fertiggestellt worden. Diese Entwürfe, die von vier Gruppen der grossen Maschinenbau Gesellschaften unterbreitet wurden, basieren auf dem Calder Hall Reaktor, werden jedoch eine Reihe von wichtigen Verbesserungen aufweisen. Die Stärke der Druckbehälter ist auf 76,2 mm erhöht worden, um einen grösseren Kern mit entsprechend besserer Neutronen Wirtschaftlichkeit zu ermöglichen, ferner mit einer grösseren Gleichmässigkeit des Neutronenflusses. Die thermische Wirtschaftlichkeit der Anlage wurde durch grösseren Druck des Kühlmittels und durch höhere Betriebstemperaturen auf ungefähr 28% erhöht, und die Ausrüstung des Werkes zum Laden und Entladen ist jetzt so konstruiert, dass die Operationen vorgenommen werden können, während der Reaktor unter voller Belastung arbeitet. Dies wird eine grössere Verbrennungszahl ermöglichen, die zur Zeit auf 2.500 MWD/T geschätzt wird.

El Programa Futuro de Energía Nuclear en Gran Bretaña

Se han ultimado ya los planos de los reactores que habrán de integrar la primera etapa del programa de energía nuclear en Gran Bretaña. Estos diseños que han sido sometidos por cuatro grupos de importantes empresas ingenieriles se basarán en el reactor de Calder Hall, pero incluirán buen número de importantes mejoras. El espesor del recipiente de presión se ha aument 76,2 mm para permitir así un mayor tamaño de nucleo con la consiguiente mejora en la economia de neutrones y mejor aplanamiento del fundente. La eficacia térmica de la planta ha sida aumentada con mayores presiones de refrigerante y más altas temperaturas de operación al 28% aproximadamente y el equipo de carga y descarga ha sido dissñado para que pueda funcionar aun en pleno funcionamiento del reactor. Esto permitirá una cifra más alta de quema que los cálculos actuales sitúan en 2.500 MWD/T.



Génératrice Nucléaire de Calder Hall

LA génératrice de Calder Hall comprendra en définitive quatre réacteurs semblables, alimentant chacun quatre échangeurs de chaleur et deux turbines, et ils recevront leur eau d'une tour de refroidissement. La puissance nominale des turbines est de 21-23 MW donnant une capacité de génération totale pour Calder "A" et Calder "B" de 92 MW chacune, dont environ 20% est repassé dans le système pour fournir de l'énergie aux auxiliaires. Le rendement thermique se situe entre 20 et 21%. La station sera officiellement inaugurée de 17 Octobre par Sa Majesté la Reine, et alors l'énergie du premier système de réacteurs sera faite passer dans le réseau de distribution d'électricité britannique.

Chaque réacteur est du type refroidi au gaz, modéré au graphite, dont le combustible est de l'uranium naturel, produisant de la vapeur dans les échangeurs de chaleur sous deux pressions. Le noyau du réacteur est un cylindre octogonal droit d'environ 9,1 m de diamètre et de 6,4 m de haut, avec pas de treillis de 20,3 cm. Les canalisations de combustible sont verticales et s'élèvent à un total de 1.696, contenant en moyenne six éléments de combustible par canalisation. Ces éléments contiennent de l'uranium naturel de densité 18,7 g/cm³ sous forme de barre de 2,92 cm de diamètre et 100,2 cm de longueur. Les récipients de combustible sont en alliage de magnésium, tournés à partir du matériau solide avec une aube hélicoïdale à départ unique et fermés à une extrémité par un tampon et chapeau, et à l'autre extrémité par une pièce d'écartement et un couvercle de bout. Le diamètre intérieur et de 2,96 cm, extérieur de 3,3 cm et le diamètre des bouts d'aube est de 5,4 cm. Ils sont pourvus d'un croisillon à une extrémité avec un cône creux central pour centraliser les éléments dans la canalisation, afin de fournir trois âmes radiales pour le soulèvement et pour placer le cône mâle dans l'élément au-dessus.

Le noyau entier, pesant plus de 1.000 tonnes, est soutenu par une grille consistant en poutres en I croisées, huit dans chaque sens, soudées ensemble, et une poutre en "I" circulaire qui est soutenue par des supports dans le dôme inférieur du bac à pression, ces derniers étant soudés immédiatement en face des châssis en "A"—10 au total—qui supportent la structure. Ces châssis en "A" sont construits avec des surfaces de support courbes pour permettre une action de roulement lors de la dilatation thermique du bac tout en maintenant en même temps de façon exacte la ligne centrale du bac.

Le bac à pression, d'un diamètre intérieur de 11,3 m, est construit sur les lieux en plaques d'une épaisseur de 5 cm en acier "Lowtem" fabriqués par Consett Iron Co. Ltd. Les extrémités en forme de dôme sont de la même épaisseur, donnant une pression de travail de 7,1 kg/cm². Le volume total du bac est de 1.630 m³. La tubulure d'entrée pour les quatre tuyaux d'acide carbonique a un diamètre de 3,66 m et est soudée à un dôme inférieur fini avec un anneau de compensation forgé. Les quatre tuyaux de sortie ont un diamètre de 137 cm et sont rendus plus épais aux extrémités bac à pression, l'épaisseur étant de 10 cm, et ils sont soudés dans des plaques bombées, dont l'épaisseur est augmentée à 10 autour des orifices.

Le réacteur est monté à l'intérieur d'un écran en béton octogonal d'une épaisseur de 2,13 m avec un toît de 2,43 m. A l'intérieur de cet écran se trouve l'écran thermique qui consiste en profilés de plaques d'acier d'une épaisseur de 15 cm.

L'accès aux canalisations de combustible est obtenu par le dôme supérieur et l'écran thermique supérieur, un tube de chargement ayant été prévu par chaque groupe de 16 canalisations de combustible. Ces tubes sont normalement bouchés par un tampon en acier rempli de béton et une bague de pression, ou par les groupes de tiges de contrôle d'un total de 40, ou les appareils de mesure de chambre d'ion. Les éléments épuisés sont enlevés du réacteur au moyen d'une machine de déchargement qui est montée sur rails et placée au-dessus du tube de chargement approprié. Avant ce stade, on procède à l'enlèvement du tampon écran et à l'insertion d'un tube de chargement consistant en deux longueurs de tube, dont l'une est pivotée par rapport à l'autre. La longueur rigide se loge dans un trou de broche dans la couverture en fonte à la partie supérieure du graphite, et par rotation et réglage de l'angle entre les deux tubes, n'importe laquelle des 16 canalisations servies pourra être choisie. Les éléments sont enlevé par un système de câble et benne preneuse et transférés dans un réceptacle qui pourra être abaissé dans le puits de déchargement dans un cercueil à écran pour être transporté à l'installation de traitement située à côté. L'inverse de ce processus est adopté pour le chargement.

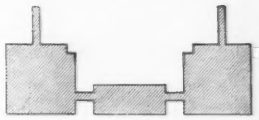
Les canalisations sont munies d'un appareillage de détection d'elements defectueux consistant en tubes en acier inoxydable de 1,25 cm purgeant une partie du gaz de refroidissement. A l'extérieur du réacteur, ces derniers sont partagés en groupes de quatre et les sorties sont amenées dans huit soupapes rotatives d'un pôle et 53 voies. Le gaz est alors fait passer par des filtres et refroidisseurs dans les groupes de précipitation où on mesure l'activité du produit de fission. On a fait les prévisions nécessaires pour l'examination continue d'une canalisation, mais au fonctionnement normal quatre canalisations par groupe sont vérifiées une fois toutes les 30 minutes.

Après des discussions prolongées il fut conclus qu'un système de vapeur à cycle double serait le plus économique. Le température de l'acide carbonique sortant du réacteur est de 336°C, et il effectue sa rentrée à 140°C. La circulation est assurée par quatre souffleurs centrifuges ayant chacun des bagues de fermeture spéciales pour empêcher l'entrée de l'huile dans le circuit du réfrigérant et de grands soufflets de dilatation suspendus a la cardan, ainsi que de grandes boucles de dilatation pour s'adapter aux changements thermiques. Les quatre échangeurs de chaleur, pesant chacun 180 tonnes et montés sur des radiers individuelles en béton situées à l'extérieur de l'édifice du réacteur, contiennent un surchauffeur à haute pression, un évaporateur et un économiseur à haute température, et un surchauffeur à basse pression, un évaporateur et un économiseur à basse pression et haute pression combinées. Sauf en ce qui concerne les longueurs du surchauffeur, les éléments de l'échangeur de chaleur ont été faits en boucles de tubes avec des projections, ces projections assurant un facteur de multiplication de surface equivalente de quatre. La surface totale est de 9.300m². A la turbine, la pression de la vapeur à haute pression est de 14 kg/cm², et la température est de 310°C. La vapeur à basse pression est à 3,7 kg/cm², et la température est de 171°C. Le rendement comprend 90.000 kgs/h de vapeur à haute pression et 27.000 kgs/h à basse pression. Dans ces circonstances, le rendement des turbo-alternateurs est de 21.000 kW.

Quoique l'organisation responsable de la conception de Calder Hall soit l'Office d'Energie Atomique du Royaume-Uni, plusieurs sociétés ont participé au développement de parties individuelles de l'installation et à la construction. Les premiers contrats furent placés pour les travaux de génie civil auprès de la Taylor Woodrow Construction Ltd., le 22 Juillet 1953, et cette organisation a fourni les ingénieurs de construction pour le chantier entier. Le bac à pression a été construit par Whessoe Ltd., qui ont été en mesure de faire appel aux conseils des Ingénieurs Conseils de l'Office en cette matière, le Lloyd's Register of Shipping. Le contrat pour les échangeurs de chaleur a été obtenu par Babcock and Wilcox Ltd, et les contrats pour les turbines, soufflerie et les gros soufflets par C. A. Parsons Ltd. Ces trois dernières compagnies s'occuperont aussi des travaux pour la génératrice du même genre à Chapel Cross, tandis que les travaux de génie civil seront entrepris par Michells Engineering. Le graphite pour le réacteur a été fabriqué par British Acheson Electrodes Ltd. et Matthew Hall and Co. Ltd. ont entrepris le montage de la pile et de nombreux circuits de tuvauterie auxiliaires. L'appareillage de chargement et de déchargement a été développée et fabriqué par Strachan and Henshaw Ltd., le système de contrôle par Metropolitan-Vickers Electrical Co. Ltd., et l'appareillage de détection des lingots éclatés par Plessey Nucleonics Ltd.

La liste précédente des entrepreneurs est loin de les représenter tous et la liste complète comprend des sociétés bien connues telles que Distillers Ltd. qui a fourni l'acide carbonique, J. Blakeborough and Sons Ltd. qui ont fourni les soupapes a grands conduits, English Electric Co. Ltd. responsables de l'installation de commutation, etc. Un grande partie des travaux de soulèvement exécutés sur le chantier a été entreprise par Costain-John Brown Ltd., qui peut maintenant se flatter d'avoir exécuté un des plus grands et hauts travaux de soulèvement en Europe.

En Octobre, un système de réacteur aura été terminé, et on s'attend à ce que le second système destiné à compléter Calder Hall "A" soit délégué en Mars 1957. Le premier système de Calder Hall "B" entrera en fonctionnement environ 12 mois après et la station sera finalement terminée six mois plus tard.



Calder Hall Atom-Kraftwerk

DAS Calder Hall Kraftwerk wird, wenn es fertig ist, vier gleichartige Reaktoren besitzen, die jeder mit vier Wärme-Austauschern in Verbindung stehen, die zwei Turbinen speisen; Wasser wird von einem Kühlturm geliefert. Die Turbinen haben eine Leistung von 21-23 MW und erzeugen, wenn sie mit Vollast arbeiten, für Calder "A" and Calder "B" je 92 MW, von denen ungefähr 20% in das System zurückgeleitet werden, um Kraft für die Hilfsmaschinen zu liefern. Die thermische Wirtschaftlichkeit liegt zwischen 20 und 21%. Das Werk wird offiziell am 17 Oktober von Ihrer Majestät der Königin eröffnet werden, wenn das erste Reaktor-System in das brittische Elektrizitäts-Netz eingeschaltet wird, um elektrische Kraft zu liefern.

Jeder Reaktor ist ein gasgekühlter, mit Graphit als Bremsstoff arbeitender Reaktor, in welchem natürliches Uranium als Brennstoff dient, um Dampf in den Wärme-Austauschern in zwei Druckstufen zu erzeugen. Der Kern des Reaktors ist ein gerader achteckiger Zylinder von ungefähr 9,1 m Durchmesser und 6,4 m Höhe; das Netzwerk hat eine Steigung von 20,3 cm. Die Brennstoff-Kanäle sind senkrecht, und es sind im ganzen 1.696, die im Durchschnitt sechs Brennstoff-Elemente in jedem Kanal haben. Diese Elemente enthalten natürliches Uranium von einer Dichte von 18,7 g/ccm in Gestalt von Stangen von 2,92cm Durchmesser und 100,2cm Länge. Die Grenstoff Hülsen sind aus einer Magnesium Legierung aus dem Vollen gedreht mit einer eingängigen Schaubenrippe; sie sind an dem einen Ende mit einem Stopfen und einer Kappe verschlossen und am anderen Ende mit einem Abstandshalter und einer Schlusskappe. Der innere Durchmesser ist 2,96cm, der äussere 3,3cm und der Durchmesser an der Kante der Schraubrippe 5,4 cm. Sie sind an dem einem Ende mit einer Spreitze mit einem Hohlkegel in der Mitte versehen, um die Elemnt im Kanal zu zentrieren; die Spreitzen bieten drei radiale Rippen zum Angreifen beim Heben und ermöglichen das Ausrichten mit Hilfe des Kegels, des darüber befindlichen Elements.

Der ganze Kern, der über 1.000 t wiegt, ist auf einem Gitterwerk aufgebaut, der aus sich kreuzenden I-Trägern besteht und zwar acht in jeder Richtung, die zusammen und mit einem kreisförmig gebogenen I-Träger verschweisst sind, der im unteren Dom des Hochdruckbehälters auf Tragarmen ruht, die direkt angeschweisst sind gegenüber den "A"-Rahmen—im ganzen 10—die die Konstruktion tragen. Diese "A"-Rahmen sind mit nach einer Kurve geformeten Lagerflächen hergestellt, um eine Art rollende Bewegung des Behälters bei der Expansion unter Wärme zu gestatten, ohne dass dies einen Einfluss auf die Beibehaltung der absolut genauen Lage der Mittellinie des Behälters hat.

Der Hochdruckbehälter von 11,3 m innerem Durchmesser ist auf dem Bauplatz aus 5 cm starken Blechen von Consett Iron & Co. Ltd. in "Lowtem" Stahl zusammengebaut. Die domartigen Kopfenden haben die gleiche Stärke bei einer Beanspruchung von 7,1 kg/cm². Der Gesamtinhalt des Behälters ist 1.630 m³. Das Einlass-Verteilerrohr für die vier Kohlensäure-Leitungen hat einen Durchmesser von 3,66 m und ist mit dem unteren Dom und einem geschmiedeten Ausgleichsring verschweisst. Die vier Auslassleitungen haben einen Durchmesser von 1,37 m und sind an den zum Druckbehälter zu liegenden Enden auf 10 cm verstärkt und in schalenförmige Platten eingeschweisst, deren Stärke auf 10 cm um die Rohröffnungen herum erhöht ist.

Der Reaktor ist im Inneren eines achteckigen Betonschirmes von 2,13 m Stärke montiert, der mit einem Dach von 2,43 m versehen ist. Im Innneren dieses Schirmes befindet sich der thermische Schirm, der abschnittweise aus 15 cm starken Stahlplatten zusammengesetzt ist.

Der Zugang zu den Brennstoff-Kanälen erfolgt durch den oberen Dom und den oberen thermischen Schirm; für je 16 Brenstoff-Kanäle ist immer ein Laderohr vorgesehen. Diese Rohre sind normalerweise mit einem Stahlstopfen, der mit Beton ausgefüllt ist, und mit einer Hochdruck-Dichtungsscheibe abgeschlossen oder mit den Kontrollstab-Einheiten im Ganzen 40, oder mit einem Ionenkammer-Messapparat. Ausgebrannte Elemente werden vom Reaktor mittels einer Entladungs-Maschine entfernt, die auf Schienen montiert ist und über dem entsprechenden Laderohr eingestellt wird. Bevor dies geschieht, wird der Schutzstopfen entfernt, und ein Laderohr eingesetzt, das aus zwei Rohrteilen besteht, die durch ein Dreh-Gelenk miteinander verbunden sind. Der feste Teil wird in ein mit einem vorstehenden Rand versehenes Loch eingesetzt das sich in dem gusseisernen Deckel oben über dem Graphit befindet, und dann kann durch Einstellung des Winkels zwischen den beiden Rohrteilen jeder der 16 Kanäle nach Wahl bedient werden. Die Elemente werden durch einen Kabel- und Greifer-Mechanismus entfernt und in einen Aufnahmebehälter überführt, welcher in den Entladungsgraben heruntergelassen wird, wo er in einen abgeschirmten Behälter kommt, um zum benachbarten Windscale-Verarbeitungswerk weiter transportiert zu werden. Das umgekehrte Verfahren wird für den Ladevorgang angewendet.

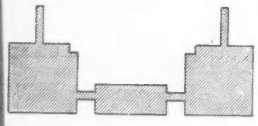
Die Kanäle sind mit einer Apparatur zum Entdecken von gebrochenen Hülsen versehen, die aus 1,25 cm Rohren aus rostfreiem Stahl besteht, durch die eine Spur des Kühlgases abgezweigt wird. Ausserhalb des Reaktors sind diese in Gruppen von vier unterteilt, und das ausströmende Gas gelangt dann in acht Drehverteiler zur wahlweisen Verbindung von 53 Einlassöffnungen mit dem Auslass. Das Gas ist dann weitergeleitet durch Filter und Kühler zu den Niederschlags-Apparaten, wo die Aktivität der Spaltprodukte gemessen wird. Es ist Vorsorge getroffen, um einen Kanal fortdauernd überwachen zu können, in normalem Betrieb werden jedoch vier Kanäle in einer Gruppe geprüft und zwar einmal alle 30 Minuten.

Nach längerer Diskussion kam man zu dem Schluss, dass ein System mit doppeltem Umlauf am wirtschaftlichsten sein würde. Die Temperatur der Kohlensäure ist 336°C beim Austritt und sie ist 140°C beim Wiedereintritt. Die Zirkulation erfolgt durch vier Zentrifugalgebläse, die mit speziellen Dichtungsscheiben versehen sind, um den Eintritt von Oel in den Umlauf des Kühlmittels zu verhindern; sie sind mit Expansionsbälgen, die in grossen Doppelringen montiert sind, und mit grossen Expansionsschleifen versehen, um thermischen Veränderungen Rechnung tragen zu können. Die vier Wärme-Austauscher, die je 180 t wiegen und auf gesonderten Beton-Gerüsten ausserhalb des Reaktor Gebäudes stehen, umfasen einen Hochdruck Ueberhitzer, einen Verdampfer und einen Vorwärmer für hohe Temperaturen und einen Niederdruck Ueberhitzer, Verdampfer und kombinierten Niederdruck und Hochdruck Vorwärmer. Abgesehen von den Niederdruck Abteilungen sind die Elemente der Wärme-Austauscher aus Schleifen von gebuckelten Rohren hergestellt, wobei die Buckel eine Oberfläche bieten, die das Vierfache der glatten Fläche darstellt. Die gesamte Fläche ist 9.300 m². In der Turbine hat der Hochdruck Dampf einen Druck von 14 kg/cm² bei einer Temperatur von 310°C. Der Niederdruck Dampf hat 3,7 kg/cm² Druck und eine Temperatur von 171°C. Der Hochdruck Dampf Verbrauch beträgt 90.000 kg/h, während der Niederdruck Dampf Verbrauch 27.000 kg/h beträgt. Unter diesen Bedingungen ist die Leistung der Turbo-Dynamos 21.000 kW.

Wenn auch die für den Entwurf des Calder Hall Werks verantwortliche Organisation die United Kingdom Atomic Energy Authority ist, so haben doch viele Gesellschaften an der Entwicklung der einzelnen Teile der Anlage und an der Konstruktion miteearbeitet. Den ersten Auftrag für die Bauingenieur Arbeiten erhielt die Taylor Woodrow Construction Ltd. am 22 Juli, 1953, und diese sind dann die Bauingenieure für die gesamte Bauanlage geblieben. Der Hochdruck Behälter wurde von Whessoe Ltd. entwickelt, die die beratenden Ingenieure von Lloyd's Schiffs-Register, die als Berater der "Authority" wirken, zur Beratung heranziehen konnten. Den Auftrag für die Wärme-Austauscher erhielten Babcock and Wilcox Ltd. den Auftrag für die Turbinen, Gebläse und schweren Bälge C. A. Parsons Ltd. Diese letzten drei Gesellschaften werden auch an der Arbeit für das ähnliche Werk in Chapel Cross teilnehmen, während die Bauingenieur-Arbeiten dort von Mitchells Engineering unternommen werden. Graphit für den Reaktor ist von der British Acheson Electrodes Ltd. hergestellt worden und Matthew Hall & Co. Ltd. übernahmen den Aufbau des Kerns und der zahlreichen Rohrleitungs-Systeme. Die Lade- und Entladungs-Apparatur wurde von Strachan & Henshaw Ltd. entwickelt und hergestellt, die Kontroll-Einrichtungen von der Metropolitan-Vickers Electrical Co. Ltd. und die Apparate zum Entdecken von geborstenen Hülsen von Plessey Nucleonics Ltd.

Diese obenstehende Liste ist aber durchaus nicht eine vollständige Liste aller beteiligten Werke; eine vollatändige Liste würde u.a. die Namen von so bekannten Gesellschaften enthalten wie I.C.I., die die Kohlensäure liferten und einige weitere Wäreme-Austauscher usw., J. Blakeborough & Sons Ltd., die die grosen Kanal-Ventile lieferten, die English Electric Co. Ltd., die für die Schalteinrichtungen verantwortlich ist usw. Ein grosser Teil der schweren Hebearbeiten auf der Baustelle wurde von der Costain-John Brown Ltd. unternommen, die jetzt den Ansbruch erheben kann, eine der grössten und höchsten Hubleistungen in Europe ausgeführt zu haben.

Im Oktober wird das eine Reaktor System fertig sein, und das zweite, das Calder Hall "A" vervollständigen soll, wird voraussichtlich in März, 1957, in Auftrag gegeben werden. Das erste System von Calder Hall "B" wird etwa zwölf Monate später in Betrieb sein, und das Werk wird dann endgültig sechs Monate danach fertig sein.



La Estacion de Energía de Calder Hall

LA Central de Calder Hall finalmente consisttirá de cuatro reactores similares, cada uno alimentando cuatro cambiadores de calor y dos turbinas, con suministro de agua desde una torre de enfriamiento. El régimen de las turbinas es de 21-23 MW dando una capacidad generadora total para Calder "A" y Calder "B" de 92 MW c/u, de los cuales el 20% aproximadamente se alimenta nuevamente dentro del sistema para suministrar energía para los aparatos auxiliares. La eficiencia térmica es entre 20 y 21%. La Central será oficialmente inaugurada el dia 17 de octubre próximo por Su Majestad, la Reina Elizabeth, en cuyo momento el primer sistema reactor será enchufado dentro de la red británica de electricidad.

Cada reactor es del tipo que utiliza uranio natural como combustile, enfriado por gas, y moderado por grafito, que genera vapor en los cambiadores de calor a dos presiones. El núcleo del reactor es un cilindro octagonal derecho de aproximadamente 9,1 m de diámetro por 6,4 m de altura, con una distancia entre barrotes de 20,3 cm. Los canales de combustible son verticales y comprenden 1.696 en total, y contienen un promedio de 6 elementos de combustible por canal. Estos elementos contienen uranio natural de una densidad de 18,7 g/cc en la forma de varillas de 2,92 cm de diámetro y 100,2 cm de longitud. Los recipientes de combustible son de aleación de magnesio, torneados de la pieza sólida con una aleta helicoidal de una sola partida y sellados en una extremidad con un tapón y casquillo y en la otra extremidad con un espaciador y tapa. El diámetro interior es de 2,96 cm, exterior de 3,3 cm, y de los extremos de aleta de 5,4 cm. Se hallan provistos de una araña a una extremidad con un cono hueco central para centralizar los elementos en el canal y proveer tres almas radiales para objectos de alzamiento y para localizar el cono macho en el elemento de arriba.

El núcleo completo, que pesa más de 1.000 toneladas, se halla apoyado en un enrejillado que consiste de vigas "I" cruzadas, ocho en cada dirección juntadas a soldadura y a una viga "I" circular, la que se halla apoyada sobre consolas en la parte abovedada inferior del recipiente de presión, siendo éstas juntadas a soldadura inmediatamente en frente de los bastidores "A"—un total de 10—que soportan las estructura. Estos bastidores "A" están construidas con superficies de soporte curvas para permitir un movimiento de rodadura durante la expansión térmica del recipiente, entretanto al mismo tiempo manteniendo exactamente la línea de centro del recipiente.

El recipiente de presión, con diámetro interior de 11,3 m se fabrica en sitio de planchas de 5 cm de espesor hechas por la Consett Iron Co. Ltd., de acero "Lowtem". Los extremos abovedados son del mismo espesor, dando una presión de trabajo de 7,1 kg/cm². El volúmen total del recipiente es de 1.630 m³. El múltiple de admisión para los cuatro conductos de dióxido carbónico es de 3,66 m de diámetro estando soldado sobre una bóveda inferior acabada con un anillo compensador forjado. Los cuatro conductos de salida son de 137 cm de diámetro, con un aumento de espesor en los extremos del recipiente de presión a 10 cm y se hallan soldados dentro de planchas embutidas, el espesor de las cuales ha sido aumentado a 10 cm alrededor de las lumbreras.

El reactor se halla montado dentro de una protección octagonal de hormigón de 2,13 m de espesor con techo de 2,43 m. Dentro de esta placa de protección está la placa de protección térmica que consiste de secciones de planchas de acero de 15 cm.

El acceso a los canales de combustible se obtiene a través de la bóveda superior y la placa de protección térmica superior, habiéndose provisto un tubo de carga para cada 16 canales de combustible. Estos tubos son normalmente punzonados por un tapón de acero relleno de hormigón y un casquillo de presión o con las unidades de varilla de control, a un total de 40, o aparato de medición de cámera de iones. Los elementos gastados se retiran del reactor por medio de una máquina de descarga, la que está montada sobre rieles y posicionada sobre el tubo apropiado de carga. Antes de ésto se retira el tapón de protección y se inserta un tubo de carga que consiste de dos secciones de tubo, una de las cuales está pivoteada relativamente a la otra. La sección rígida está posicionada en un orificio de espiga en la cubierta de hierro fundido en la parte superior del grafito y, por rotación y ajuste del ángulo entre los dos tubos, cualquiera de los 16 canales servidos puede ser seleccionado. Los elementos se retiran mediante un sistema de cable y garra, transfiriéndose a un depósito que puede ser bajado por un pozo de descarga a un cofre protegido para ser transportado a la planta de procesado Windscale que queda junta. Para el cargado se adopta el mismo procedimiento a la inversa.

Los canales se hallan provistos de aparato de detección de elementos defectuosos que consiste de tubos de acero inoxidable que desangran alguna parte del gas enfriador. Al exterior del reactor estos se hallan divididos en grupos de cuatro, las salidas alimentadas dentro de ocho válvulas rotativas de un polo y 53 vías. Se hace pasar el gas entonces a través de filtros y enfriadores dentro de las unidades de precipitación en donde se mide la actividad de producto de fisión. Hay disposición para el examen contínuo de un canal, pero en el servicio normal se verifican cuatro canales en un grupo una vez cada media hora.

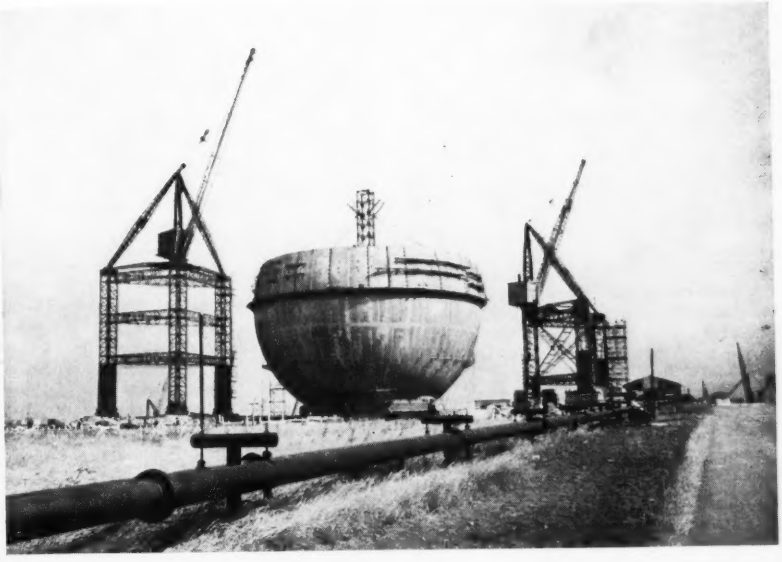
Después de mucha discusión, se llegó a la conclusión que el sistema más económico sería uno de ciclo doble de vapor. La temperatura del dióxido carbonico que sale del reactor es de 336°C y entra de nuevo a una temperatura de 140°C. Se provee la circulatión mediante cuatro sopladores dentrífugos, cada uno con casquillos especiales de sellado hermético para evitar el ingreso de aceite dentro del circuito de enfriamiento y con grandes fuelles montados en suspensión cardánica y grandes lazos de expansión para hacer frente a cambios térmicos. Los cuatro cambiadores de calor, cada uno con un pesi de 180 toneladas, montados sobre placas de cimentación individuales de hormigón de alta presión al exterior del edificio del reactor, un evaporador y un economizador de alta temperatura y un supercalentador de baja presión, un evaporador y un economizador de baja y de alta presión combinadas. Aparte de las secciones del supercalentador, los elementos del cambiador de calor han sido construídos con lazos de tubos con salientes, proveyendo los salientes un factor de multiplicación de área de superficie equivalente de cuatro. El área total es de 9.300 m². En la turbina, la presión de alta presión de vapor es de 14 kg/cm², y la temperatura es de 310°C. El vapor de baja presión es de 3,7 kg/cm² y la temperatura de 171°C. El rendimiento comprende 90.000 kg/hr de vapor de alta presión y 27.000 kg/hr de baja presión. En estas circunstancias, el rendimiento de los turboalternadores es de 21.000 kW.

Mientras que la autoridad competente en el diseño de Calder Hall es la Autoridad Atómica del Reino Unido, muchas compañías se han dedicado al desenvolvimienti de las piezas individuales de la planta y de la construcción. Los primeros contratos para las obras de ingeniería civil fueron colocados con la firma Taylor Woodrow Construction Ltd., el 22 de julio de 1953, y dicha firma han sido los ingenieros constructores de todo el lugar de la obra. El recipiente de presión fué evolucionado por Whessoe Ltd., cuya firma ha podido valerse de los consejos de los consultores de la Autoridad, Lloyd's Register of Shipping. El contrato de los cambiadores de calor fué obtenido por Babcock & Wilcox Ltd., y los contratos de las turbinas, sopladores y fuelles por C. A. Parsons Ltd. Estas trés últimas compañías también se dedicarán a obras para la central similar de Chapel Cross, mientras que el trabajo de ingeniería civil correrá a cargo de la Mitchells Engineering. El frafito para el reactor ha sido fabricado por British Acheson Electrodes Ltd., y Matthew Hall and Co. Ltd. corrió a cargo de la edificación de la pila y numeros circuitos de tuberías ancilarias. El equipo de carga y de descarga fué evolucionado y fabricado por Strachan and Henshaw Ltd., el sistema de control por Metropolitan-Vickers Electrical Co. Ltd., y el equipo de detección de elementos defectuosos por Plessey Nucleonics Ltd.

Esta lista dista mucho de ser completa, y la nómina completa de contractores incluye firmas tan conocidas como Distillers Ltd., que suministró el dióxido carbónico, J. Blakeborough and Sons Ltd., cuya firma puede jactarse actualmente de haber desem-Electric Co. Ltd., responsables por los cuadros de distribución, etc. Gran parte del trabajo pesado de izamiento que se llevó a cabo en el lugar de la obra corrió a cargo de Costain-John Brown Ltd., cuya firma puede jactarse actualmente de haber desempeñado una de las obras más importantes y a mayores altitudes de izamiento que se haya hecho hasta la fecha en Europa.

En octubre próximo se habrá terminado un sistema de reactor y el segundo sistema para completar Calder Hall "A" se espera que sea comisionado en marzo de 1957. El primer sistema de Calder Hall "B" estará en servicio unos 12 meses más tarde y la central se terminará finalmente seis meses después de esa fecha.

World News



The Dounreay reactor, now scheduled for operation in early 1958. The biological shielding inside has been completed and work is proceeding on the upper half of the sphere. Designed to generate 60 MW heat, this reactor may become the prototype for a series of fast-breeder power stations. Shielding information will be more readily obtained with the operation of LIDO the swimming pool research reactor at Harwell which went critical on September 20.

INTERNATIONAL

Sensational statements on the health dangers of atomic energy came under heavy fire from Dr. J. V. Dunworth of A.E.R.E., Harwell, at the World Federation of United Nations Associations. He described a lot of the recent reports as ill-informed and usually unfounded and referred to the very high standard of safety operating in atomic energy plants in the U.S. and the U.K. He made the plea that international health standards should not be made unduly restrictive so as to create a considerable hindrance to the development of economic power and the general utilization of atomic energy. Whilst it is undeniable that international standards should be set on safety and a strict watch kept on developments, because of international health implications the sensational aspects of radiation hazards can too easily create an atmosphere in which a realistic and practical approach to the problems is difficult.

A grant of $400,000 offered by the Ford Foundation has been accepted recently by CERN. It is to be spent over five years to help in strengthening co-operation in nuclear physics research primarily with the United States and other countries not members of CERN. The grant is expected to be used mainly to enable professors to come and work with CERN and to give young scientists opportunities for working in its laboratories.

The United Nations Conference to discuss the international agency for atomic energy met at U.N. headquarters on September 20. Twelve nations approved the draft charter of the agency earlier in the year. Timed to coincide with the conference, a permanent exhibition was opened at the headquarters. Included in it was an accurate scale model of the Calder Hall power station.

Euratom nations meeting in Brussels to discuss both the Atomic Energy Organization and the proposed customs-free market have set up a study association to plan, as a joint enterprise, a gas diffusion plant for enriching uranium. In spite of the considerable offers by the United States for the supply of U 235 and the prospect of resonable quantities of plutonium being available from graphite-moderated, gas-cooled piles, the diffusion plant is considered to be the first main project that Euratom should undertake. It is estimated that the project could be completed in the space of about four years.

UNITED KINGDOM

SIMA exhibited a comprehensive range of British equipment on a stand covering 5,000 sq. ft. at the St. Erik's Fair, Sweden, from September 1 to 17; 34 firms took part. In the nuclear field the exhibits included thickness gauges, dosemeters, radiation monitors, ion chambers and a wide range of laboratory instruments.

The Dorset site. Investigations into the direction and speed of ocean currents in the neighbourhood of the expected outfall of the effluent pipe from the new atomic energy site at Winfrith Heath, Dorset, are drawing to a conclusion. These have followed the pattern of the original tests carried out off the coast of Cumberland before the erection of the plutonium production plant at Windscale. Concentration of active material in seaweed will be less of a problem in Dorset, as none is collected on that coast for human consumption.

Cross-channel link. The Central Electricity Authority and Electricité de France have received from the joint committee, set up to consider a possible connection between the electricity networks of the two countries, a recommendation to adopt a scheme for the interchange of energy by direct current by means of a single cable capable of transmitting between 120 and 150 MW at 200 kV. The project, which is estimated to cost about £4 million, could be completed and ready to go into operation in 1960 if no further difficulties arise. Tests have been going on since 1953 on the feasibility of such a scheme, which has been made practicable largely by the development of high-voltage cables. The 100-kV interconnection between Sweden and the island of Gotland has provided valuable data. One advantage of a D.C. rather than an A.C. system is that it allows the two countries to independently regulate frequencies, and to regulate the free load interchange with greater precision.

The Engineering Marine and Welding exhibition has changed its title to the Engineering Marine Welding and Nuclear Energy exhibition. The first exhibition held under the new title will be at Olympia in London from August 29 to September 12, 1957. In the past the same exhibition was known first as the Engineering and Machinery exhibition and then for many years as the Shipping Engineering and Machinery exhibition.

The Harwell reactor school has now been extended to cater for a greater influx of students. Sir John Cockcroft opened the new building on September 10 at the commencement of courses 7 and 8 which will last six and 14 weeks respectively. Similar pairs of courses are scheduled to begin on February 4, June 3 and September 16, 1957. The short course is an innovation and represents the first half of the standard three-months' course.

AUSTRIA

The Austrian Study Society for Atomic Energy Research has announced that it will be asking tenders for the installation of an experimental reactor within the next few months. Its present tentative programme calls for the completion of construction within 18 months to two years. At present no indication has been given of the supplying country and it is expected that both the United States and the United Kingdom will be asked to make proposals.

CANADA

Fuel-elements manufacture is to be undertaken by industry. A long-term contract has been awarded to A.M.F. Atomics Canada Ltd., a subsidiary of American Machine and Foundry Co. General Smith, president of the Canadian company, has stated that construction of the new plant would be commenced shortly. This would consist of a 30,000 sq. ft. factory on a 30-acre site at Port Hope. It is expected to be operating at full capacity early in 1957, and the plant will be extended to provide facilities for the manufacture of equipment of all types applicable to a reactor programme.

Radiation analysis has been used to determine the quantity of arsenic in the hair of a man believed to have been murdered. This is thought to have been the first use of isotope techniques by the police in any country. For the record, however, it should be noted that the tests indicated that the original diagnosis of heart attack was probably correct.

Work began on the site for Canada's new experimental power laboratories on September 19. The ceremony was attended by a number of foreign diplomats including the Soviet Ambassador. The site is 3 miles south of the Ontario Hydro-Electric Power Commission's Des Joachims generating station on the Ottawa river.

FINLAND

Reactor for process steam. Two representatives of the Atomic Power Company of Finland have visited the United Kingdom to study nuclear power developments. The chairman of this company, Mr. Erkki Aalto, has announced that the intention is that the first station should be operating by 1960. Inquiries have been sent both to the United States and the United Kingdom and it is likely that detailed discussions can begin shortly. An interesting side to the company's interest is that the main requirement is for steam generating plant for application in the pulp industry, with electricity output a secondary consideration. It is becoming apparent that those countries rich in forest, such as Norway, Sweden and Canada and now Finland, are primarily interested in atomic energy for process steam and the market for reactors, capable of producing this economically will be considerable.

A uranium rush was forecast towards the end of August to the small village in central France called Azat-le-Riz, when an engineer reported considerable activity on the surface corresponding to possibly one of the world's richest veins of uranium. Special government authority had to be invoked before mining could begin, as the vein was thought to lie underneath the property of an unco-operative army officer. However, by the first week in September a shaft had been dug 160 ft. without any results, and interest in the project is steadily dying down. An early Reuter report stated that the engineer who discovered the vein had announced to the Atomic Energy Commission that his "geiger counter had registered observations at between 30 and 31 elections per second".

ITALY

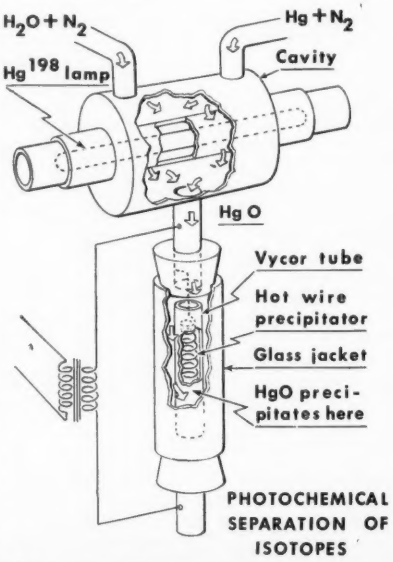
An atomic energy bill will be presented to Parliament towards the end of the year, outlining the government's proposals for the development of atomic energy in Italy. Preliminary reports indicate that the government will reserve the right to control developments and will only permit private ownership of fissile material under specialized conditions. Governmental power will be invested in a national committee for nuclear energy, which, it is thought, will have wider powers than the U.K.A.E.A. but will be modelled on similar lines.

JAPAN

A hundred tons of Zirconium figured in a recent barter deal between Japan and the U.S.A.E.C. for surplus agricultural products. Both the Ishizuka and the Osaka Titanium Company are engaged in pilot-plant testing and the first of these is expected to start production early next year. Supply is expected to be 20 tons per month at a rate of $12 to $14 per lb. Large titanium production facilities will enable full-scale zirconium production to be started soon.

RUSSIA

Broadcast in U.S.A. Progress on a controlled thermo-nuclear reaction was hinted at by Professor Emelyanov in a recent broadcast in America. The talk was one of a series of radio reports by leading experts on developments in their own countries. No details, however, were given and no real indication of the progress that had been made. He confirmed the figure previously given that the total capacity of the nuclear power stations to be built in the Soviet Union during the next five years would be between 2,000 and 2,500 MW.



Schematic arrangement of the apparatus used to separate Hg 198 from natural mercury. It is hoped that the system might be applicable to uranium.

SWITZERLAND

An agreement with the Soviet Union for the exchange of information and facilities in the atomic energy field may be discussed shortly. Some dissatisfaction has been expressed with the present Swiss-United States agreement concerning the limitations imposed on the use of fissile material. Apart from the swimming-pool reactor exhibited at the Geneva Conference and which remained in Switzerland, a heavy-water materials-testing reactor is being constructed by Reactor Ltd., a company formed by Brown Boveri, Baden, Escher Wysss, Zürich, and Sulzer Bros., Winterthur, founded on March 1, 1955. The reactor is scheduled to have a heat output of 10 MW and is provided with a number of experimental holes and facilities for hot loop experiments.

UNITED STATES

Isotope separation is the subject of a patent recently awarded to Baird Associates Atomic Instrument Co. This system is based on the development of a method of separating mercury isotopes using a mono-isotopic resonance lamp as the light source for a photochemical reaction. With mercury, enrichments on a single pass of 1.5 have been achieved. Research into the separation of uranium isotopes is only in preliminary stages.

D_2O - sodium - reactor project. The U.S.A.E.C. announced on August 28 that approval had been granted for the negotiation of a contract for limited initial design and development work on a reactor system proposed jointly by Chugach Electric Association, of Anchorage, Alaska, and the Nuclear Development Corporation of America. The proposal, which was made under the power demonstration reactor programme, is for a power reactor of 10 MW electrical capacity using heavy water as moderator, liquid sodium as coolant and slightly enriched uranium as fuel. The project has been divided into three phases, covering initial design; final development in engineering design; and construction, start-up and operation. It is proposed that after completion of each phase the three parties will have the option of determining whether the results of the completed work justify continuation. Initial contribution by the A.E.C. is expected to be about $2¼ million, rising to over $18 million for the completed project. Of this, $5½ million would be for the reactor itself for which the Commission would retain title. These figures and estimates of generation costs do not include any charge for fissionable material or heavy water. The Electric Association would provide reactor site, generating facilities, etc., and a capital cost of just under $2 million has been estimated.

N.D.A. claim many advantages for the sodium - cooled, deuterium - moderated system including the ability to work on only lightly enriched uranium. This is considered to be of particular value for reactors which have to operate in such remote areas as Alaska or which are destined for export. A long fuel-element life leading to burn-up figures approaching 50% U 235 with a conversion factor of

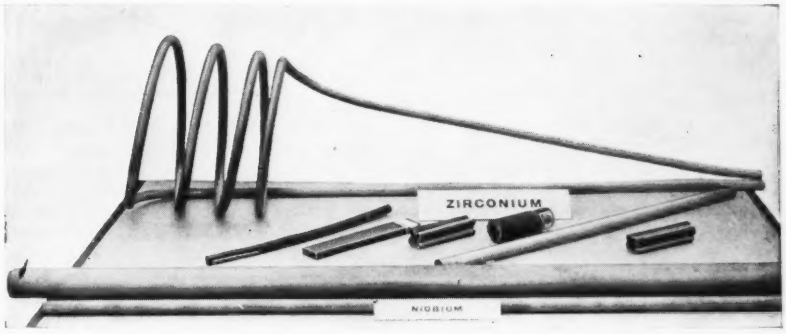
0.75 and a 25% burn-up of plutonium is envisaged. Further advantages are high coolant temperatures and low pressures, leading to an efficient steam cycle and a simplified and safe control system based on the level of D_2O in the system. The company also claims that, with full development of this type of reactor, a cost of 7 mills per kWh in plants of 10 MW capacity is possible.

Present proposals indicate that the Chugach reactor will consist of a tank of heavy water 6-8 ft. in diameter holding an array of stainless steel pipes each containing a cluster of stainless steel-clad uranium rods ¾ in. in dia. and 6 ft. long. These pipes, which carry the liquid sodium, are thermally insulated from the surrounding moderator. Shielding would be by graphite and a 10-in. iron shield, outside which would be erected the normal concrete biological shield. It is expected that fuel enriched to approximately 1½% will be used. In addition to the system, two other proposals for small-capacity power plants have already been approved as a basis of contract negotiations. These are the Rural Co-operative Power Association, Elk River, Minnesota, for a closed-cycle boiling-water reactor plant with an installed capacity of 22 MW and Wolverine Electric Co-operative, Big Rapids, Michigan, for an aqueous homogeneous reactor plant with an installed capacity of 5-10 MW. Four other proposals still under consideration by the Commission come from the City of Holyoke Gas and Electricity Department, Holyoke, Mass., for a gas-cooled reactor with a closed-cycle gas turbine and an installed capacity of 15 MW; the City of Orlando, Florida, for a liquid-metal-fuelled reactor with an installed capacity of 25-40 MW; the City of Piqua, Ohio, for an organic moderated reactor with an installed capacity of 12½ MW; and the University of Florida, Gainesville, for a pressurized-water reactor with an installed capacity of 2 MW.

The Brush Beryllium Co., Cleveland, Ohio, has announced the award of a contract from the A.E.C. to supply 250 tons of reactor-grade beryllium over a five-year period beginning January 1, 1958. As a result, a new plant is to be built adjacent to the present beryllium copper alloy division near Elmore, Ohio. Cost of this expansion is estimated at approximately $4½ million. Brush claims to be the only industrial producer of reactor-grade beryllium metal in the United States and is at present operating the A.E.C. facility at Luckey, Ohio.

The first industrial-sponsored international conference on reactor technology was held from August 27 to September 1 at the General Atomic Division, General Dynamics Corporation, in San Diego, California. Representatives from Japan, Sweden, Italy, France, Israel and Austria took part and Great Britain was represented by Dr. P. Fortescue, of A.E.R.E., Harwell, who, in company with Dr. Lewis, director of Atomic Energy of Canada Ltd., has been making a tour of a number of American facilities.

Leaks have developed in the steam-superheating system of *Seawolf*, reports Reuter, *Seawolf* is the second nuclear-powered submarine built for the navy and is at present under dockside test in Connecticut. It is believed that the equipment affected was outside the reactor proper, although it is understood that faulty welds have been one of the major troubles in the development.



These examples of zirconium and niobium seamless tubes were shown by Accles and Pollock Ltd. at the S.B.A.C. Flying Display and Exhibition, Farnborough. See paragraph "Aeronautics and Atomics" overleaf.

A petroleum loop has been installed in the reactor at Brookhaven National Laboratory by the Atlantic Refining Co. to permit experimentation on the effects of radiation under refining conditions. It is hoped from these experiments that an accurate appraisal can be made of the economic possibilities of using nuclear radiations in full-scale petroleum refining, and it is hoped that new petroleum products will be discovered.

The Nuclear Energy Property Association, made up of about 155 capital-stock property insurance companies, has been now qualified as an underwriter by New York State Insurance Department and is offering coverage up to $50 million through regular brokerage channels for single reactor risks. It is possible that other companies will join the Association. Third-party liability coverage as provided by stock casualty companies will be underwritten by the Nuclear Energy Liability Association.

Combustion Engineering Inc. has received a contract from the U.S.A.E.C. to build a $10 million prototype nuclear plant for a submarine on the lines of development undertaken by General Electric. The contract includes construction of a submarine hull replica for training naval personnel.

A new assistance programme has been launched in order to assist in the education of students of nuclear engineering. Arrangements are being made for special materials to be loaned without charge for use in the fabrication or preparation, and by-products materials will be furnished at 20% of list price. Certain other materials peculiarly related to nuclear energy technology will be furnished without charge. An upper limit of $50,000 has been put on the value of such materials. Under the terms of a second programme, the Commission will make grants towards the cost of the acquisition of equipment to be used on nuclear engineering courses, a limit to grants having been placed to any one institution of $350,000.

A peculiar comment was made by Dr. W. F. Libby at a recent meeting of the American Chemical Society on the potential use of plutonium, in which he challenged scientists to discover a way of using this nuclear fuel. He went on to point out that increasing stock piles of this material would soon satisfy military requirements and that unless it could be put to some useful purpose considerable wastage would result. Dr. Libby, however, cannot be ignorant of such programmes as the fast reactor project at Dounreay, which admittedly will be initially fuelled with U 235, but which is able to take an experimental core of plutonium, nor of the proposals to combine depleted uranium with plutonium for graphite-moderated reactors. The metallurgy of plutonium still requires further investigation and handling problems are acute, but there is no justification for his statement that the use for plutonium as a power fuel "would be nearly zero".

MEETINGS AND EXHIBITIONS

October 2-10—Fuel Efficiency Exhibition.

October 18.—Tees-side Section: "A Nuclear Power Station and its Instrumentation", K. R. Sandiford.

October 19.—West of Scotland Iron and Steel Institute Conference on Application of Low Alloy Steels for Welded Pressure Vessels.

October 29-*November* 2.—International Ferrite Convention, Institution of Electrical Engineers, Savoy Place, London, W.C.2.

November 22.—Institute of Marine Engineers, West Midlands Section: "Nuclear Engineering", J. A. Kendall. Society of Instrument Technology, Newcastle Section: "Instrumentation of Nuclear Reactors", T. R. Thompson.

December 17-19.—Physical Society Autumn Meeting, Edinburgh University, β and γ Ray Spectroscopy.

December 18.—Rutherford Lecture. Professor P. I. Dee. The α-particle.

Orbits in Industry

Coincidence at Calder

Someone recently pointed out to this column, as an example of coincidence, that vapour clouds issued from the cooling towers at Calder Hall three years to the day that the first turf-cutting party moved on to the site. A far more interesting coincidence, however, does not concern Calder Hall itself so intimately as it does one of the companies responsible for a large part of the work, as it is just three-quarters of a century since they were building corresponding plant for a very distant ancestor of Calder Hall.

In a brochure, "Holborn Viaduct to Calder Hall", an advance copy of which has come our way, Babcock and Wilcox give a fascinating account of their connection with the steam-raising end of electricity supply from the world's first power station to the first atomic power station—both definitions being qualified. Calder is the first atomic station to give power on a commercial scale—Holborn Viaduct gave the first public supply that was not solely for arc lighting. The organization is to be congratulated on this production. The history of the electrical industry is pretty thinly documented and, brief as this must obviously be, it is nevertheless an acceptable addition. Particularly striking is the artist's reconstruction of the original station; it has more hidden detail in it than a Giles cartoon.

Behind the Boron Curtain

There should be some red faces in the A.E.A. if anyone has read the letter from a contemporary in the September 14 issue of *World's Press News*. Headed "Ten Hours in a Train—For What?", it records the feeling of a technical journalist who went on the August 10 trip to Calder—laid on specially for the technical Press—and has had the courage to state his opinions, with which most of us, who spent exactly 24 hours away from London for practically nothing, would agree. The impression gained, in fact, is that the A.E.A. is sharply divided into two schools, the Wellingtons ("Publish and be damned!") and the George Robeys ("Ush! Ush! I *will* 'ave 'ush"!!).

This trip for the technical Press would appear to have been an unhappy compromise between the two factions. The technical Press was shown Calder at a smart trot (total time two hours, including questions). The unfortunate part of this schizophrenic attitude is that it is not confined to the A.E.A., but extends downwards throughout the industry. Contractors have become so used to asking permission to speak that it has become automatic. If they are dealing with "Ushers" they not only refuse to say anything about their own part in the story, but they, in turn, suppress their sub-contractors until the supplier of galvanized nuts and bolts is almost afraid to say whether they were Whitworth or B.S.F. What makes it even more difficult to understand is that some of the sealed-lips brigade are connected with equipment that has no direct connection with the nuclear side, but is straightforward engineering material. The result will be that a great many manufacturers will lose all chance of a share in—whatever one may say—one of the technical stories of the century.

Many individuals in the A.E.A. have done their very best in this situation; it is difficult to see how they could have been more helpful and the Press, as a whole, is sincerely grateful. There is, however, still a hard core of those who seem to feel that Calder Hall should be an esoteric mystery; something reserved for the privileged few. They must be made to realize that, unless there is some overwhelming reason for security—and it is difficult to see how this can be a matter of national importance at this stage—their proprietary attitude is based on a very doubtful title.

Aeronautics and Atomics

Preoccupation with Calder, however, was not allowed to interfere with a visit to Farnborough in early September and observation of the growing interest of suppliers to the aircraft industry in nuclear materials. That organization of a thousand aliases, Accles and Pollock, showed their usual ingenuity in seamless tube production with a display of various sections in zirconium, including flexible tubing, and tubes in niobium, one example of which has a diameter of 0.674 in. and a wall thickness of 0.022 in. Extrusions in beryllium, zirconium and thorium were shown by the Chesterfield Tube Co. Ltd.

Elektron lightweight magnesium-zirconium alloy castings, sheets, extrusions and forgings were featured by Magnesium Elektron Ltd. and included the new thorium-containing, creep-resistant, high-strength alloys ZT1 and TZ6. Other companies showing examples of magnesium-zirconium castings included Birmingham Aluminium Casting (1903) Co. Ltd., Kent Alloys Ltd., Sterling Metals Ltd. and J. Stone and Co. (Charlton) Ltd.

Stainless steel bellows in a wide variety of diameters were displayed by Teddington Aircraft Controls Ltd. and Avica Equipment Ltd.; the latter has supplied flexible stainless steel piping and bellows to the A.E.A.

Accidents in Industry

Sky Press Ltd. have sent a copy of a booklet "Safety and Health in Industry", which is distributed to visiting safety officers at the Industrial Health and Safety Centre, 97 Horseferry Road, Westminster, London, S.W.1. If anyone still imagines that industrial accidents are all due to being "caught up in the machinery" the foreword by the Chief Inspector of Factories should dispel the illusion, while the book shows with imagination and realism some of the accidents that can happen. In addition to this text-book in miniature, the advertisement pages form a truly representative buyer's guide to the range of safety equipment and protective clothing available. Single copies, it is stated, can be obtained from the Director of the Centre.

New Home for Pullin

Measuring Instruments (Pullin) Ltd have moved into new premises at 93-97 New Cavendish Street, London, W.1, a building of contemporary design that provides a landmark in that neighbourhood. Believed to be the only curtain-wall office building in London, Electrin House, as it has been named, provides accommodation for all the units of the group, including R. B. Pullin and Co. Ltd.; Measuring Instruments (Pullin) Ltd.; The Pullin Optical Co. Ltd.; Stanley Cox Ltd.; Donvin Instruments Ltd.; and Victoria Instruments Ltd.

Addresses

Other changes of address recently notified include Nuclear Research Applications Ltd., who have moved from 5 Victoria Street to Emefco House, Bell Street, Reigate, Surrey, their telephone number being Reigate 5341.

The Battelle Institute Ltd. announce that their registered office is now at 24 Ryder Street, St. James, S.W.1. Telephone TRAfalgar 1621.

Elliott Bros. (London) Ltd. have asked us to point out that their Nuclear Division is located at their Lewisham establishment, Century Works, London, S.E.13, and not at Boreham Wood with their Computing Division.

Elliotts, incidentally, have recently concluded an agreement with Swartwout of Cleveland, Ohio, by which they become manufacturing licensees and sole agents in the British Commonwealth (except Canada) for "Autronic" control and transmission equipment.

Training Courses

Bradford Technical College is running a course on "Nuclear Energy applied to Electrical Engineering" by B. Fozard, B.Sc. (Hon.), on Thursdays, 7 to 9.30 p.m., throughout the session.

The Heriot-Watt College, Edinburgh, is to run a course of six lectures on "Power Generation by Nuclear Reactors", for six Saturday mornings (9.30 to 12) starting on October 20. The lecturers are J. H. Bowen, B.Sc., A.M.I.E.E. (U.K.A.E.A., Industrial Group, Risley); W. H. J. Childs, Ph.D., D.Sc., F.Inst.P., F.R.S.E. (Professor of Physics, Heriot-Watt College, Edinburgh); J. M. Kay, M.A., Ph.D., A.M.I.Mech.E. (Professor of Nuclear Power, Imperial College of Science and Technology, London); W. L. Kidd, B.Sc., M.I.E.E., A.M.I.C.E. (South of Scotland Electricity Board, Glasgow); and A. B. McIntosh, B.Sc., Ph.D., F.R.I.C., A.R.T.C., F.I.M. (U.K.A.E.A., Culcheth).

Northampton Polytechnic, E.C.1 is commencing a series of 22 lectures on "An Introduction to Nuclear Power". The lectures are at 7 p.m. Monday evenings, commencing on October 8, and are given largely by staff from A.E.I.'s research laboratories.

New Books

Progress in Nuclear Energy (Series I), —Physics and Mathematics, Vol. 1. *Edited by R. A. Charpie, J. Horowitz, D. J. Hughes and D. J. Littler. (Pergamon Press Ltd., London,* 1956, 84*s.*)

This book contains the most complete collection of physical data and account of mathematical techniques relating to the calculation of critical assemblies which has so far appeared in a single volume.

A number of well-known physicists have contributed chapters, based on papers they have presented at the recent Geneva International Conference. The sections by Bethe, on the analysis of neutron resonances, and that by Bernstein and Smith, on the energy dependence of the cross-section of Xe 135, have been reprinted from the published papers of the Conference, while the remaining sections consist of rearranged and amplified material from the Conference papers.

The field covered includes reviews of available data on absorption and fission cross-sections and resonance structure of U 233, U 235 and Pu 239, experimental techniques for neutron resonance in the epithermal region. A long review of the properties of delayed neutrons is followed by a collection of experimental critical data on aqueous solutions of U 233, U 235 and Pu 239.

The last three chapters are of a mathematical nature and treat methods of critical size calculation with a comparison between calculated and experimental results for fast reactors, heterogeneous lattices and highly enriched thermal assemblies.

Each chapter is followed by a fairly complete list of references, and these are extensively referred to in the text.

J. F. PEARSON.

Progress in Nuclear Energy (Series II) —Reactors Vol. 1. *Edited by R. A. Charpie, D. J. Hughes, D. J. Littler and M. Trocheris (Pergamon Press, London & New York,* 1956, *X* + 482 *pages,* 100*s. net.)*

The contents of this book, the first of the reactor series in the "Progress in Nuclear Energy" publications, fall naturally into two parts dealing respectively with research reactors and power reactors.

Descriptions, drawings and photographs are given of research reactors which are in operation throughout the world, as well as the uses to which they have been put. Although most, if not all, of this information is available elsewhere, the collecting of it into one book facilitates a comparison of objectives, methods and results—a comparison which is made more valuable by the inclusion of Russia's work. The lead over the European continental countries which the United States possesses by virtue of her ability to tackle material irradiation problems in the M.T.R. is clear for all to see. The authors of the chapter on Canada's Research Reactors give an interesting survey of the N.R.X. faults and accidents.

The second half of the book deals with some power reactors which are either being constructed or seriously considered. A fuller description of Calder Hall, comparable to the excellent one given of the Shippingport Reactor would have pleased your reviewer, but doubtless this will be forthcoming. The describers of the Shippingport Plant deserve special praise for the balance, level of approach and illustrations in this chapter. The list given on pages 333 and 334 of some of the mechanical mockups and tests carried out on this reactor gives some idea of the amount of development required, and which is not always apparent, except to those responsible for design and construction.

A chapter is included on the design and operating experience of a prototype boiling water reactor. It is generally agreed that, more than any other fixed-fuel reactor, the control problems of boiling reactors need data which are only obtainable from reactor experiments or prototypes. The inclusion of the results of these classic experiments is therefore very welcome.

Descriptions are given of aqueous homogeneous and sodium graphite reactors. In discussing such reactors based on advanced and as yet unproven technologies it is essential to distinguish between a so-called "conceptual design" and a workable engineering design. This distinction is not clearly made here. In the case of the aqueous homogeneous reactor it would be fairer to list some of the unknown technological problems.

The book is well produced and profusely illustrated. Local nomenclatures have been retained with the result that the terms "buckling" and "laplacian" both appear with their respective symbols, and three different sets of units are used for heat flux density.

W. MURGATROYD.

Progress in Nuclear Energy. (Series III) —Process Chemistry, Vol. 1. *Edited by F. R. Bruce, J. M. Fletcher, H. H. Hyman, J. J. Katz. (Pergamon Press Ltd., London,* 1956.*) (U.S.A. Edition published by McGraw-Hill Book Co. Inc., New York.) XIII* + 407 *pages,* 84*s.*

This volume is the first of what is intended to be an annual series of publications on progress in the process chemistry of nuclear energy. Other aspects of the nuclear energy field are covered in seven other series.

The eight chapters of the book cover, respectively, the extraction of uranium and thorium (from their ores), radiochemical separation processes, reactor fuel dissolution, chemical principles of radiochemical solvent extraction processes, wet processes for radiochemical separations, the separation of uranium by volatilization as uranium hexafluoride, pyrometallurgical processes, and isotope production and fission product treatment. There are 36 papers in all, 15 are new while the others are revised versions of papers originally presented at the Geneva Conference in 1955 in some cases with important additions.

For example, the first paper dealing with the extraction of uranium from its ores deals much more extensively than the corresponding Geneva paper with the use of solvent extraction in ore processing, and describes recent developments in the solvent extraction of slurries and the direct leaching of ores with organic solvents after a pugging treatment with sulphuric acid.

The major part of the book deals with the processing of fuel elements and it is natural that the emphasis should be on solvent extraction processes which are now well established and well tried. The story is almost complete and there is little lacking but full details of specific flowsheets. The field is surveyed, the problems defined and the translation of processes from the laboratory to the pilot plant dealt with from the viewpoint of experience.

Despite the success and ubiquity of solvent extraction processes, it must be remembered that the first successful process was the bismuth phosphate process and Thompson and Seaborg give an interesting account of the now historic work on what was then a new element available in less than μg quantities.

Solvent extraction has the apparent disadvantage that the irradiated fuel must be dissolved and go through a long series of processes before it is ready for return to the reactor cycle. Methods which can produce the fluoride ready for reduction to metal in a few steps, or which retain the fuel in the metal phase offer the prospect of processing economies and may also enable a saving of cooling time which would reduce capital charges in fuel.

The volatility of uranium hexafluoride is exploited in processes using fluorine, bromine trifluoride, chlorine trifloride, these processes are still in the development stage and while the chemistry is fairly well understood the technical difficulties are great.

The homogeneous aqueous reactor presents processing problems of a different nature from those of the metal-fuelled reactor and is dealt with in a paper by Ferguson.

Fission product wastes are good sources for the isolation of radioisotopes, and the last chapter deals mainly with the process chemistry of the extraction of radioisotopes from gaseous and liquid wastes.

Two appendices give useful information on fission product chains, including the fission yield, and a third describes a convenient method of estimating the amounts of fission products present for various times of irradiation and cooling of the fuel with results displayed in a series of graphs. A short glossary and an index complete the book.

The book presents as balanced a picture of chemical processing as one could expect and in a much more easily handled form than the Geneva papers. The editing and general production is good but the index is only fair and the glossary seems redundant in these days.

A. S. WHITE.

Elements of Pulse Circuits *by F. J. M. Farley, M.A., Ph.D. (Cantab.) (Methuen and Co. Ltd. 6½ in. x 4 in. 143 pp. 74 Illus. 8s. 6d. net).*

Possibly the best description that could be found for this book is the well-known tag applied by the I.E.E., to lectures . . . "This is an Integrating Paper." This simple description enables one to place the scope and level of the treatment at once; it will cover the field competently and thoroughly and not focus its energies on dealing with one narrow aspect of the subject with ever-increasing complexity.

The author has assumed that the reader is reasonably familiar with valves and elementary radio techniques and his approach is almost entirely non-mathematical throughout. Commencing with the basic concepts of pulse waveforms, integration and differentiation, the book proceeds to fundamental valve circuits and to square wave generators of various types. Then follows chapters devoted to trigger circuits, time bases and pulse amplifiers, after which applications of the various principles already explained. Throughout, the author's concern is that the reader should understand the physical principles involved and be able to apply them rather than on mathematical analysis. This should result in the book having a wide appeal.

Progress in Nuclear Energy (Series IV), —Technology and Engineering, Vol. 1. *Edited by R. Hurst and S. McLain. (Pergamon Press Ltd., London, 1956.)*

This book is mainly a selection of Geneva Conference papers and therefore contains much valuable material. Many of them are by authors of standing and comprise as good surveys of the fields covered as has yet been produced. Some of the papers have been regrouped and shortened to the readers' advantage. The sections are entitled: Heavy Water, Graphite; Beryllia; Liquid Metals; Engineering (the term is here synonymous with heat transfer); Reactor Chemistry and Corrosion.

It is stated on the dust cover that no better introduction to these series could be conceived than critiques and summaries of the proceedings of the Conference. With this view few would disagree and it is a pity that the design of this first volume of an important series on nuclear technology is not in accord with it. The papers are, in the main, as printed for the conference, including errors of translation and misprints and with no indication of some of the more important points raised in discussion. For example, in "Heat Transfer by Molten Metals" by M. A. Mikheyev, *et al.* the value 1.5 is subtracted from the Nusselt Number to allow for surface fouling. The newcomer to the subject would profit by reference to the discussion on this point. Again, the statement in "Heat Transfer by Compressed Gas in the Saclay Pile" by J. Yvon, that in a power reactor "the vital temperature is the average temperature of the primary coolant since this fixes the thermal efficiency" should have had at least an editorial footnote.

There is no doubt that the collection of these papers in one volume is a convenience to the reader and even at the price of four guineas the book will be used by many in preference to the more expensive official United Nations publication.

J. DIAMOND.

Personal

Lord Reith has been appointed a director of the British Oxygen Co. Ltd.

Mr. A. J. Brunker, B.Sc. (Eng.), A.C.G.I., D.I.C., A.M.I.E.E., chief engineer of E. K. Cole Ltd., has been appointed an executive director of the company.

Sir Herbert Manzoni, chairman of council of the British Standards Institution, was elected the first president under a new arrangement of combining the two formerly separate offices of president and chairman of the general council. He succeeds **Sir Roger Duncalfe**, chairman of the British Glues and Chemicals Ltd. **Mr. John Ryan**, vice-president of the Metal Box Co. Ltd., was re-elected vice-president of the B.S.I.

Dr. J. Pearson, Ph.D., M.Sc., F.R.I.C., assistant director of the British Iron and Steel Research Association, has taken charge of the Sheffield laboratories, retaining the headship of the Steelmaking Division but relinquishing control of the Chemistry Department, for which **Mr. E. W. Voice**, head of the Ironmaking Division, will become responsible. **Mr. R. Mayorcas** has been appointed deputy head of the Steelmaking Division. **Mr. J. G. Wistreich**, head of the Metal-working Laboratory, has become head of the Mechanical Working Division, as **Mr. W. C. F. Hessenberg**, deputy director of BISRA, is to relinquish control of this division to devote the whole of his time to his other duties. **Mr. S. S. Carlisle**, head of the BISRA South Wales laboratories, has been appointed deputy head of the Division.

Mr. Airey Neave, D.S.O., O.B.E., M.C., Member of Parliament for Abingdon, Berks (the constituency which includes Harwell), has joined John Thompson Ltd. as legal adviser. Mr. Neave, who has relinquished his appointment as parliamentary private secretary to Mr. Lennox Boyd, Colonial Secretary, will spend some weeks at the Wolverhampton works before establishing himself at the company's London office.

Mr. W. J. Parker has joined Mervyn Instruments in charge of sales of infra-red spectrometric and polarographic equipment.

Dr. Richard Filipowsky, who joined the Westinghouse Electric Corporation's electronics division, advance development section, last year, will receive the British Institution of Radio Engineers' Heinrich Hertz Premium in October in recognition of his technical paper "Electrieal Pulse Communication Systems" published last year.

Mr. Joseph P. Gordon has been appointed assistant director of the tube research division of Allen B. Du Mont Laboratories Inc. Mr. Gordon was previously the division's administrative assistant and manufacturing department manager. **Mrs. Alice Close** has been appointed export manager of the international division and **Mr. Peter Weil** assistant manager of the technical products division.

Mr. G. C. Oram, manager of the central engineering workshops at Appleby-Frodingham Steel, Scunthorpe, has been additionally appointed technical consultant, engineering works, to the United Steel Companies.

Mr. C. J. O. Garrard, M.Sc., M.I.E.E., has been appointed manager of the General Electric Co. Ltd.'s switchgear and transformer works group at Witton. **Mr. J. S. Cliff**, M.I.E.E., has been appointed manager of the switchgear works at Witton.

Mr. J. R. Phillipson and **Mr. V. A. Kennett**, joint managing directors of Plannair Ltd., and **Mr. E. W. Randle**, technical director, welcomed nearly 200 guests at the company's first garden party held in the grounds of the head office at Windfield House, Leatherhead, on September 8.

Mr. F. L. Field has been appointed assistant sales management, and **Mr. J. Connell** assistant to the sales manager, of the plant department of Metropolitan-Vickers Electrical Co. Ltd., consequent upon the contracts department ceasing to exist as a separate entity.

Mr. E. E. Sanford has been appointed administrative manager of Vitro Engineering Division, part of Vitro Corporation of America. He was previously administrative manager of Vitro Laboratories Division.

Mr. David H. G. Ince, D.F.C., B.Sc., has joined British Oxygen Arc Equipment Ltd. as sales manager. Mr. Ince was formerly concerned with aircraft sales and technical liaison at Elliott Brothers (London) Ltd.

Mr. G. B. Foote has been named assistant treasurer of Baird Associates-Atomic Instrument Co., Cambridge, Mass. Mr. Foote was formerly administrative director of operation for the Detroit Controls Corp.

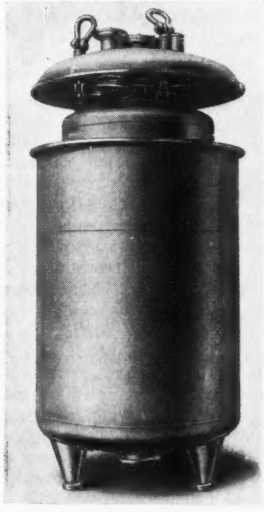
Mr. Derek du Pré has been appointed joint secretary of the Institute of Cost and Works Accountants. **Mr. S. J. D. Berger**, M.C., F.C.I.S., director and secretary of the Institute, continues to hold this office. Mr. du Pré will relieve Mr. Berger of some of his secretarial responsibilities.

Mr. S. B. Roberts has been appointed general sales manager of Heavy Minerals Co., New York. Mr. Roberts has been executive vice-president and a director of International Selling Corp., New York, and will retain his position as director.

Processes and Equipment

Liquid Nitrogen Storage

W. P. Butterfield Ltd., of Shipley, Yorks, have produced a new liquid nitrogen storage tank for use where consumption exceeds the capacity of small bottles or flasks. Designed in conjunction with Dr. D. H. Parkinson, Dr. J. M. Lock and Mr. W. A. Hoyes of the M.O.S., the unit holds 300 gallons. The insulation problem, normally one of considerable difficulty with a temperature of −196°C, has been met by the combination of a vacuum jacket and



The new Butterfield liquid nitrogen storage unit.

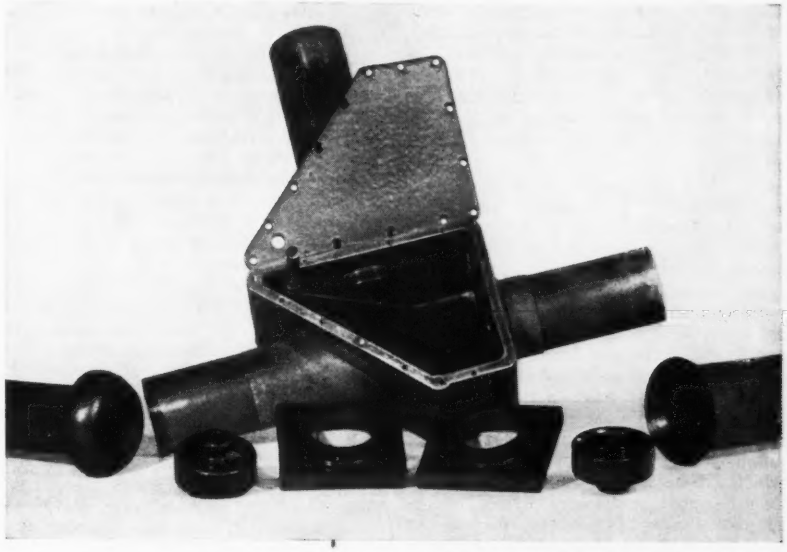
powder insulation to protect against conduction and radiation respectively.

The vessel itself is of stainless steel, with a mild steel jacket, the vacuum being of the order of 0.1 mm., with a negligible air leak. Conduction through fittings and supports has been reduced to the minimum by reducing their cross-section as far as possible and using materials of low conductivity.

Tests conducted on a 300-gal. tank of liquid nitrogen have shown that the evaporation is only of the order of 2 gal./day. Larger vessels have been supplied.

Plastic Coatings

Problems in design can often be resolved by the combination of metal and plastics, thus combining the strength of, say, steel with the corrosion or abrasion resistance of plastics, such as polythene, nylon, P.V.C. and P.T.F.E. Hydralon Ltd., of Millbrook Industrial Estate, Southampton, are in a position to treat metal parts in this manner and the accompanying illustration shows a typical example. This is a gas exhaust valve used on a commercial vehicle to divert the flow of exhaust gas as required, to warm a tarmacadam container, preventing premature solidification in cold weather or to heat the driver's cab.



Parts of a gas exhaust valve with plastic coatings.

A variety of techniques are used, involving shot-blast preparation of the metal surface to give a key, the preheating of the part, the application of the coating by dipping into paste or liquid, spraying in powder form, or dipping into an agitated dispersion. Precise heat control is necessary. The coating is then cured by further heat treatment in an oven.

Metal Rectifier Welding Set

The Quasi-Arc range of welding sets has been extended by the addition of a new model for single-operator duty. Known as the M.C.R. 375, it incorporates a three-phase bridge-connected, selenium rectifier giving a stable arc of high power factor (0.8) and balanced loading of supply mains.

Suitable for voltages of 360/440, the unit has an open-circuit voltage of 64. The normal maximum continuous current is 250 amp., with a maximum of 375 amp. at 35 arc volts. Stepless control is provided over the range 30/375 amp. by a moving core choke operated by a control handle in the housing, with a calibrated drum to show the current setting. The complete unit, with interlocked cooling fan, contactor with push-button control, instruments and casing, weighs just over 8 cwt. and can be supplied mounted on floor skids or with a four-wheel undercarriage. It has class A insulation, is constructed to B.S. 171/1936 and 638/1954 where applicable, and is suitable for electrodes from 16 S.W.G. to ¼ in.

Long-life Valves

Precise control of material quality and manufacturing processes, coupled with several interesting design features, are stated to be the reason for the L. M. Ericsson Ruggedized-Longlife miniature electronic tubes being sold with a guaranteed minimum life of 10,000 hours. A complete catalogue of the range has been received from State Labs. Inc., of 649 Broadway, New York, 12. Latest in the series is the 5847/404A, a high-transconductance 9-pin tube, intended for low-noise amplifier service and capable of withstanding high impact shock and vibration.

Nylon Plunger for Microswitch

Burgess Products Co. Ltd., of Team Valley, Gateshead, 11, announce that their

The new Burgess V3 switch.

V3 Micro Switchette is now being produced in an improved version, the operating plunger now being made in nylon, giving increased life expectation as well as the self-lubricating characteristics of nylon. The price remains the same.

Patents Reviewed

These abstracts have been made from British Patent Specifications, complete copies of which can be obtained from the Patent Office, 25 Southampton Street, London, W.C.2, at 3s. each (including postage).

B.P. 749,680. Treatment of polymeric substances. A. Charlesby. To: U.K. Atomic Energy Authority.

If long chain polymeric substances of alternate silicon and oxygen atoms, having substituents attached to the silicon atoms, are subjected to ionizing radiation by gamma rays, high energy neutrons, deuterons, helium ions, protons, electrons in a thermal nuclear reactor appreciable cross linking of the polymer chains will be produced.

B.P. 750,428. Scintillometer. To: Texaco Development Corp. (U.S.A.).

The small number of photo-electrons which can be provided by a simple scintillation are first utilized in a light amplifier tube where each of them is accelerated to a very high potential (30,000 V.). The accelerated electrons are then made to bombard a luminescent target (photo-electric device), which will produce a new scintillation related to the increased energy of the electrons. By this interposition of a light amplifier the number of photo-electrons which will be emitted in the photo-electric device (photo-multiplier tube; photo-sensitive Geiger-Muller tube) may be so increased that the likelihood—inherent in previous counters—of any count being lost is greatly reduced.

B.P. 753,031. Process for the production of substantially pure thorium, niobium, molybdenum, tantalum, vanadium, tungsten, chromium, uranium or boron. To: Norton Grinding Wheel Co. Ltd. (U.S.A.).

Specification No. 744,396 describes a process for the preparation of pure titanium metal by electrolytic deposition. The electrolytic cell has an anode formed of titanium carbide isolated from the cathode. The cell contains fused salt, preferably the chloride of lithium, potassium, sodium, magnesium, calcium and aluminium or a mixture of such halides. When gaseous halogen is introduced into the cell below the level of the fused salt titanium tetrahalide is formed by reaction with the titanium carbide. The steps employed in this process are also described in specification No. 747,834 for the production of zirconium or hafnium or alloys thereof from their carbides. It has now been found that pure thorium, niobium, molybdenum, tantalum, vanadium, tungsten, chromium, uranium or boron can also be produced by electrolysis of a corresponding carbide in the same way. To obtain best results current and temperature will be varied according to the particular carbide. The separation of the element from the fused salt (e.g., $UC_2 = U-2C$) may be conducted by vacuum distillation or by using an organic solvent. (Add. to 744,396.)

B.P. 754,012. Method of measuring variations in the distance between different points in an extensible object situated inside an opaque enclosure. A. P. Pages. To: Soc Alsacienne de Constructions Mécaniques (France).

A radioactive marking is used for checking the variations in the position of cable elements (pairs or quads) inside a telecommunication cable protected by a lead sheath and steel armour. As a marking, a wire piece is made out of a pure metal or metal alloy which is capable of partial transmutation by activation in the flux of neutrons of a nuclear reactor, into a radioactive isotope emitting a sufficiently penetrating gamma radiation to be detected by a Geiger counter. An activated fine gold wire is suggested glued in the form of a transverse marking to the cable elements inside the sheath. The activity of each marking at the time of laying is of the order of 1 millicurie. The sheathed and armoured cable was unwound and the elongation of the core under traction measured.

B.P. 754,499. Bonding of metal borides to graphite. To: General Electric Co. (U.S.A.).

The borides of the rare earth and the alkaline earth elements and thorium and uranium provide thermionic emitters with very desirable properties. They have, however, only a short life at high temperatures if the borides are supported by a metal member. This disadvantage can be overcome by using a graphite holder. The boride is placed on the holder and heated until all the boride is melted. As the boride and carbon do not chemically combine but tend to dissolve into each other, a bond surface is formed due to the interlacing of the adjacent surfaces. The hexaboride of lanthanum is preferred, although any of the rare earth metals or mixtures may be employed. The cathodes thus formed are said to have a high resistance to shock and vibration.

B.P. 754,559. Thermal nuclear reactor, in particular for aircraft propulsion. H. P. G. A. R. von Zborowski (France).

The system has a reserve of fissionable material with at least two wall portions opposite each other between which a moderator fluid can pass. The whole mass of fissionable material is chosen so that it is 1.01 to 1.1 times the "slow" critical mass (0.01 of the fast critical mass). The moderator is supplied under pressure and the rate of flow so chosen that the moderator leaves the passage in gaseous form and the multiplication factor is equal to 1 in normal running conditions. The nuclear generator then has automatically a stable output. Fig. 1 is a diagrammatic view of the reactor. R are the walls of fissionable material, and A is the passage for the moderator *F* from reservoir 1. The walls R are given the mass M (1.01 to 1.1 of the slow critical mass M_1). F is heavy water (or purified water, hydrocarbon, mixture of water and alcohol). The rate of flow is determined by the inlet pressure (cross-section of inlet S adjusted by valve 2) so that the fluid F leaves the passage A in gaseous form.

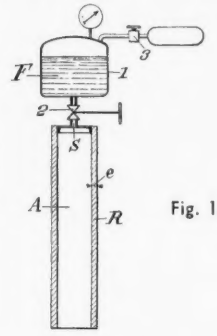


Fig. 1. B.P. 754,559.

B.P. 754,651. Method of separating plutonium. F. Morgan (Canada).

Refers to the separation of plutonium from its mixture with uranium and fission products of uranium. The mixture is formed in the neutron-irradiated rods of uranium (heterogeneous arrangement), or in the neutron-irradiated dispersion or solution of uranium compound (homogeneous arrangement). Of interest for separation are fission products of relatively long life, i.e., isotopes of zirconium, niobium, ruthenium, strontium, yttrium, cerium, praseodymium, barium and lanthanum. The total weight of these fission products is extremely small (10 g. in a 50-kg irradiated uranium rod). To separate plutonium, the mixture is dissolved in nitric acid, adding bismuth and zirconium nitrates as carrier compounds. The insoluble phosphates of plutonium, zirconium, bismuth and niobium are precipitated by adding an aqueous solution of a soluble phosphate (sodium dihydrogen phosphate) and the precipitated phosphates treated with oxalic acid. The compounds of zirconium and niobium are soluble, while an insoluble precipitate of bismuth and plutonium oxalate remains, which is separated from the solution. This separation may be effected, e.g., by treatment with hydrochloric acid.

B.P. 754,981. Method of reducing oxides of titanium and zirconium and making titanium and zirconium alloys. To: Metro-Cutanit Ltd. (Austria).

The great chemical affinity of titanium and zirconium for oxygen makes the production of the pure metal difficult. The oxides of titanium and zirconium, however, are readily reduced with carbon or silicon. Using carbide or silicide material as reducing agent, the reduction is performed under a high vacuum (10^{-3} mm. Hg.) at over 3,000°C. To form alloys, one or more metals may be added whereby alloy metals such as molybdenum, tungsten, chromium, aluminium, manganese and nickel facilitate the reaction. An electric arc furnace may be used with the reacting metals forming the electrodes.